MCR 73-21

Contract NAS1-11711

STUDY OF APPLICATION OF ADAPTIVE SYSTEMS TO THE EXPLORATION OF THE SOLAR SYSTEM

FINAL REPORT

Volume III

Mars Landed Systems

Approved

Robert B. Blizard
Technical Director

William T. Scofield
Program Manager

MARTIN MARIETTA AEROSPACE
DENVER DIVISION
Denver, Colorado 80201

FOREWORD

This is the final report on Study of Application of Adaptive Systems to the Exploration of the Solar System, performed by Martin Marietta Aerospace.

This study was performed for the Langley Research Center, NASA, under Contract NAS1-11711 between June 23, 1972 and June 8, 1973. Mr. W. Frank Staylor of the Langley Research Center was the Technical Representative of the Contracting Officer. The contract was sponsored by Planetary Programs in the Office of Space Sciences (OSS) at NASA Headquarters.

This Final Report consists of three volumes:

Volume I - Summary

Volume II - Survey of Solar System Missions

Volume III - Mars Landed Systems

ACKNOWLEDGEMENT

Martin Marietta takes pleasure in acknowledging the contributions of the following NASA personnel.

W. Frank Staylor, Technical Representative of the Contracting Officer, monitored the contract, guided the Contractor in apportioning resources to the various lines of investigation, and contributed ideas for adaptive techniques.

Edwin F. Harrison of the Langley Research Center played a large role in formulating the scope of the study and setting the ground rules for the Mars landed systems.

Paul Tarver of NASA Headquarters was one of the early supporters of the idea of adaptive systems and was instrumental in initiating the study.

CONTRIBUTORS

W. T. Scofield	Program Manager
R. B. Blizard	Technical Director
R. W. Stoffel	Computer and Software Studies
W. H. Tobey C. E. Farrell N. M. Phillips D. M. Adams	Rover studies. Mechanical systems and configurations for Mars landers.
B. C. Clark J. F. Vandrey	Science
T. W. Locke	Mission Analysis and Design
O. O. Ohlsson N. M. Phillips R. W. Stafford T. Buna A. A. Sorensen	System and subsystem studies. Structures, communications, thermal control, and power.
E. R. Cody	Cost and Schedule Studies

In addition to the above, the following people (listed in alphabetical order) contributed valuable ideas and guidance.

F. Bartko
B. A. Claussen
W. S. Cook
J. S. Derr
P. V. Fennessey
C. F. French
J. Gliozzi
H. D. Greyber
G. R. Hollenbeck
K. W. Ledbetter
J. P. Martin
R. D. Moog
W. O. Nobles
J. H. Romig
H. N. Zeiner

CONTENTS OF VOLUME III

Page

LIST OF FIGURES

Figure		Page

LIST OF TABLES

I. INTRODUCTION

Volume II described the results of the first part of the study, a look at a wide variety of solar system missions to explore the possibilities and benefits of adaptability. This volume presents the results of a more detailed study of three missions to the surface of Mars: an advanced lander, a lander with a small tethered rover, and a lander with a medium sized rover that operates independently of the lander for most of its functions but communicates with Earth through the lander. For all three missions it was assumed that the Viking orbiter and lander would be used with modifications as required to improve the science package, to accommodate the rovers, and to handle the increased payloads.

In Chapter II of the present volume, the three landed systems are described. It is shown that either a small or a medium rover can be carried on the Viking lander without major modification, although there is an increase in total weight. Communication, power, and thermal control systems are defined in enough detail to establish feasibility and permit good estimates of weight and cost. The locations of the scientific instruments are shown. Items on the advanced lander that are not on Viking '75 include a 1 meter drill, landing site selector, improved seismometer, wet chemistry, advanced biology experiment, humidity sensor, soil water tester, and an integrated geology package including a magnifier for one of the fax cameras. Rover design including hazard detection and avoidance have been carried to the point where hardware and software sizes can be determined, but no attempt was made to trade off various alternatives to arrive at an optimum design.

Chapter III covers the propulsive requirements for landing the three configurations in the baseline year, 1981, and also discusses the latitude limitations imposed by thermal extremes.

Chapter IV, "Adaptive Science" describes the scientific instruments, their objectives, and ways to increase their value with adaptability. Quantitative estimates of the benefits of adaptability were made where possible. Some of the benefits can be realized as reductions in cost as well as improved performance. In the biology experiment, for example, it is necessary to get a very tight gas valve closure between sampling times. Since soil particles can lodge in the valve, developing and qualifying a reliable valve could be extremely expensive. In an adaptive system, a leak can be detected (with instrumentation already required for the experiment) and the valve cycled until it is cleared or, if that fails, a backup valve can be closed.

Another possibility for cost reduction is in the active seismometry experiment. For good results, the seismometer would ordinarily be deployed away from the lander to minimize noise from wind and thermally induced movement. In an adaptive system, the seismic background noise can be monitored, and the seismic source can be activated when an extremely quiet period is encountered. This technique will probably make it unnecessary to deploy the detector, and the costs of deployment mechanisms, thermal control for the isolated detector, and the communication link can be saved.

A flexible adaptive system requires a central computer that has access to all the data generated by the sensors and can control all the actuators. The availability of this computer will reduce costs by taking over many of the functions that would otherwise have to be done with special purpose hardware designed, built, and qualified for the individual experiments. Typical functions that can be taken over by the computer are sequencing, data formatting, and error control coding of critical data.

Chapter V describes a control system that will perform the adaptive functions that have been identified. Individual instruments are controlled by "operating routines." The operating routines take care of the ordinary instructions that make an instrument perform, like the sequencing of a chemical processor, and the adaptive features that involve only that instrument. Also programmed into the computer is an "executive controller" that decides what operations to do at any time and provides the interactions between instruments controlled by the operating routines. For instance, when the anemometer detects a high wind, the executive controller directs the cameras to protect their optics from flying dust, increases the rate of taking meteorological data, and tells the seismometry data system not to go into the high data rate mode unless it detects quakes greater than the level to be expected from the wind shaking the lander.

The executive controller is the handle that the science team and the mission operations team will use to control the mission after landing. It is designed for easy modification and a good interface with the two teams. The science team controls the equations that determine the priorities of the many possible actions and the mission operations team determines the feasibility equations. Priorities are numbers that indicate the desirability of each action, and the feasibilities are yes-no variables that tell whether an action is safe and can be done within the power and data capacity budgets. Separating the functions relieves the science team of the responsibility for mission safety and lets them make rapid decisions with a minimum of approval, review, and verification loops.

The size of the computer memory for the executive controller and the operating routines is about 15,000 words, somewhat less than the capacity of the Viking computer.

To test the concept, an executive controller was programmed with equations for six pieces of equipment operating in 12 different modes. Chapter VI presents some simulation results from this controller with environmental events introduced by means of a random number generator. Experience with simulation showed that this type of executive controller is easy to understand and modify.

It was also found that it was difficult to write good priority equations the first time--the controller, like a computer, does what it is told to do but not always what the programmer intended. The results indicate that extensive simulation testing should be done before starting the mission to get efficient operation immediately after landing. Of course, the biggest improvements will still be made during the landed phase of the mission as more is learned about the Martian environment.

Chapter VII provides a cost analysis based on a design which would include only mandatory engineering changes. To this baseline configuration an additional 30% was added to improve the lander science. Other additional costs of 2% for the lander, 5% for the small standard rover, and 6% for the deluxe rover or 16% for the medium rover would be required depending on the selected mission.

To these costs for a non-adaptive mission, approximately 7% must be added to provide an adaptive mission. This incremental cost for adaptability is small compared to the anticipated enhancements in scientific return which run from 20% or 30% for some experiments to very large improvements in detecting transient events.

Some of the science instruments recommended in this study are not now under development in NASA's SRT program. A description of these new instruments and numerous needed rover technology items are discussed in Chapter VIII, along with desirable computer developments, both software and hardware.

There are many ways in which an adaptive system on Mars can give much more scientific value for the dollar. Today's technology is adequate for the job, but for minimum cost it is important to plan an adaptive <u>system</u> rather than trying to incorporate adaptive features into the individual experiments and subsystems.

II. SYSTEM STUDIES

This chapter describes lander and rover systems using adaptive capability integrated into Viking-derived systems. Three basic concepts of Mars landed system were considered: an advanced lander, an advanced lander with a small rover, and an advanced lander with a medium rover. These concepts involve different degrees of adaptability, versatility, and sophistication, and each has a different impact on the Viking '75 lander design. Engineering aspects of each concept were evaluated in sufficient detail to characterize their adaptive functions and to assure that the concepts were reasonable and feasible extrapolations of the Viking '75 system. The selected concepts are not intended as finalized concepts but are, rather, typical of systems within the three categories identified.

Following trade studies and definition of the three concepts, their impacts on launch vehicle, orbiter, entry, descent, and landing systems were analyzed. As discussed in Chapter III, these analyses complement the landed system study results by rounding out the feasibility assessment for the Mars missions. The concepts were then incorporated into the analyses of the character and benefits of adaptability in advanced lander and lander/rover missions as described in Chapters IV and V.

A. ADVANCED LANDER

Groundrules for the advanced lander allow it to have improved sampling ability and scientific instruments compared to Viking '75 as well as adaptability. During configuration trade studies, consideration was given primarily to providing greater sampling capability and increasing the science instrument payloads while keeping modifications to nonscience related systems to a minimum. The trade studies and the resulting typical advanced lander concept used in the subsequent adaptive mode analyses are described below.

1. Configuration Trade Studies

There are many ways to increase the sampling capabilities of an advanced lander without a rover: longer boom samplers, mortar samplers, short propulsive hops, wheeled lander mobility, drill samplers, and new sampling accessories for the Viking '75 surface sampler.

a. Longer Boom Samplers - Two types of longer booms were investigated: a six meter version of the baseline Viking '75 surface sampler and a new, ten meter concept with driven wheels on the sampler head to relieve the boom weight and sampling loads imposed on the boom and its deployment mechanism.

Growth versions of the three meter Viking '75 boom shown in Figure II-1 were examined and reported on earlier by Martin Marietta under the Viking Project (Ref. 1)*. That study produced the following conclusions regarding lengthening the boom to six meters. First, extending the length of the baseline boom could

---

* References for Chapter II are listed at the end of Chapter II.

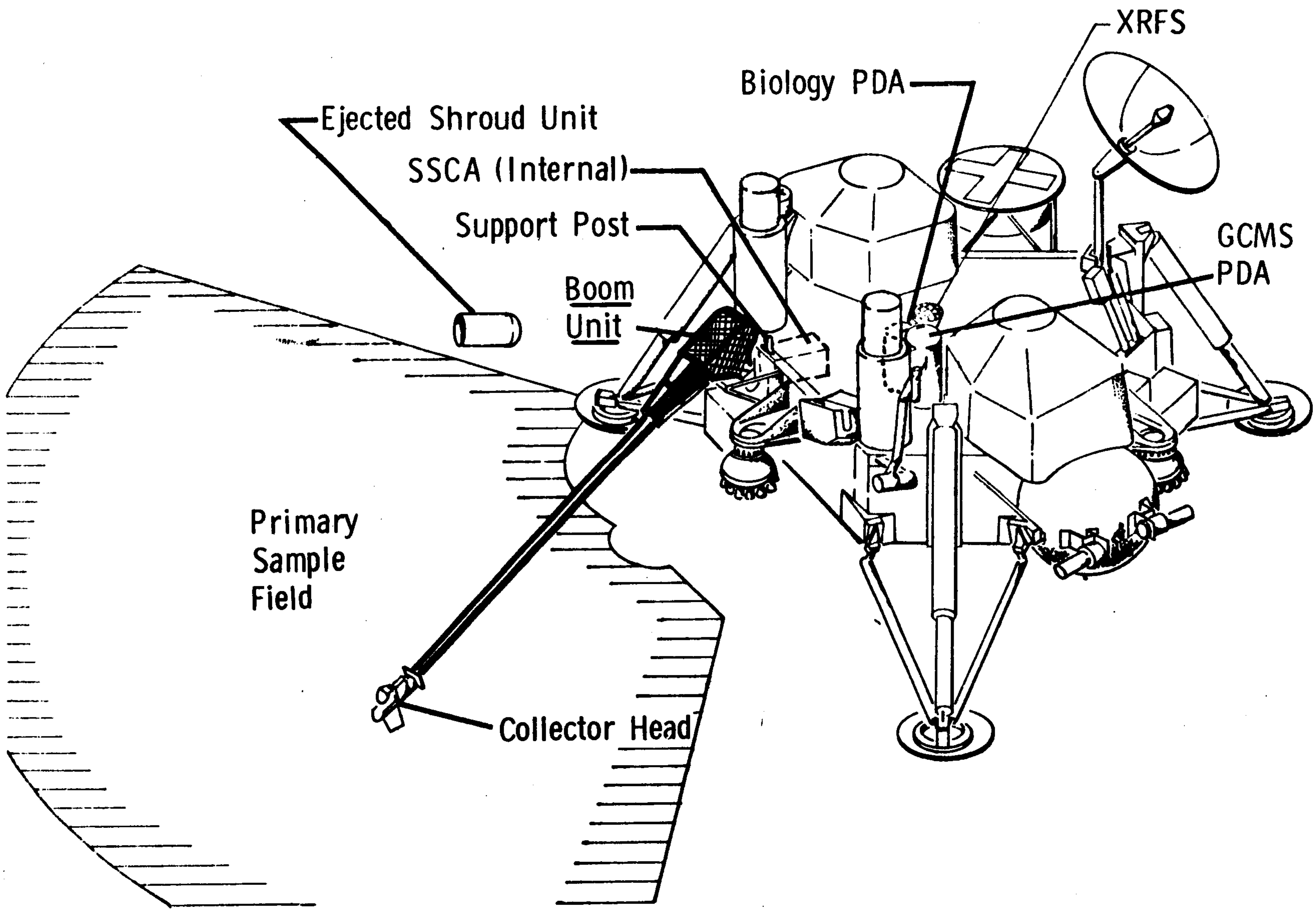


Figure II-1 Landed Configuration

be accomplished with a 30% weight increase and a 20% volume increase. However, the forces which could be applied by the sampler head (and hence the sampling capability) would be significantly reduced and samples would be obtainable, at full extension, only under the best conditions. Any difficult terrain or surface model would have to be sampled at a lesser distance. Second, a new boom assembly capable of applying baseline sampling forces at a range of six meters would require 10 kg as compared to 5 kg for the baseline boom element and deployment mechanism. However, a new load sensing system would have to be devised since the size and weight of the new boom would mask the loads from sensors of the type utilized in the baseline boom. A final conclusion was that overall reliability would be less with the longer boom.

Typical furlable boom design guidelines (Ref. 2) indicate that boom tip loading is restricted primarily by the loads which the boom can support without buckling, especially at the base where the tip loads are imposed at the longest moment arm. Therefore, methods to relieve the base support loads were investigated. The wheeled boom sampler concept illustrated in Figure II-2 was evolved as a result. This concept provides suitable base joint load relief. The boom can be deployed from either the lander or the sampler head. Deployment from the sampler end is attractive because the weight of the deployment mechanism can be used to support the vertical component of sampler-surface interface loads.

Analysis of furlable booms which could be fabricated for this application provided the following information. First, the sampler head mass, including wheels, drives, the boom deployment mechanism and furled boom, would be on the order of 10 kg or more. If this sampler head enters a depression, the boom could contact the surface, unload the wheels and, as a result, place an over-

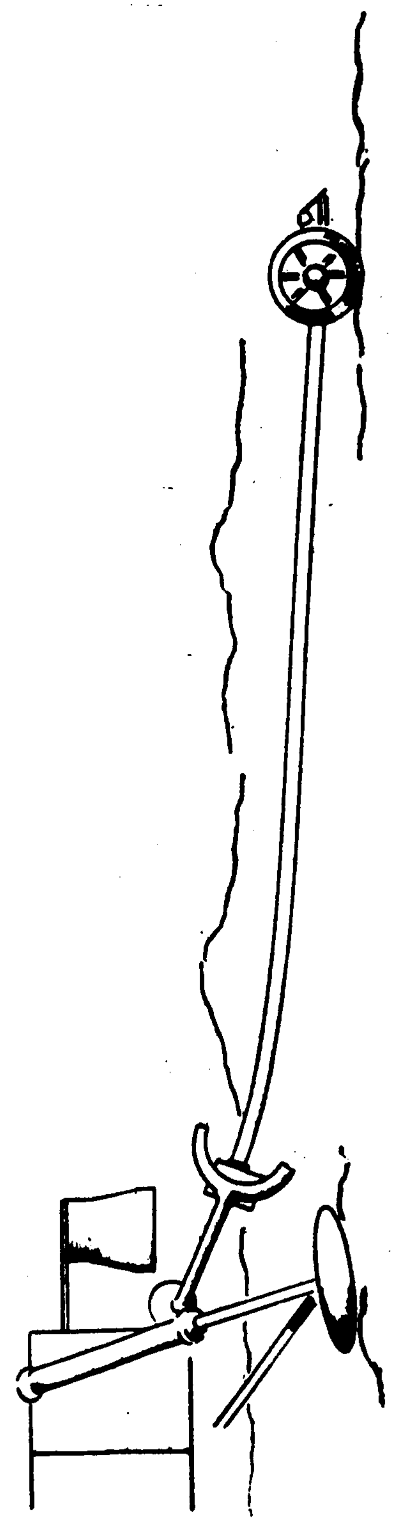


Figure II-2 Wheeled Boom Sampler

hanging tip-weight load up to 40 N (9 lbf) on the boom. The boom must support this load without buckling at the point where the boom is contacting the surface. This load is approximately equal to the maximum capability of the baseline surface sampler boom. Therefore, the wheeled sampler's boom must be approximately as large as the baseline boom. Data from Reference 1 regarding mass growth as a function of length for the baseline boom were therefore used to estimate boom and deployment system mass for wheeled boom samplers with various range capabilities. Figure II-3 illustrates this relationship. Total added mass for a wheeled boom sampler would include the mass shown plus an estimated 10 kg mass for the lander-mounted interface, the wheels and drives, and the sampling mechanism, thereby giving a mass of approximately 17 kg for a complete 10 m wheeled boom sampler.

No studies were conducted of booms exceeding 10 m length since the weights of such booms would exceed the weight of a small rover having greater sampling range and versatility (see Section II. B).

A variety of sampling mechanisms can be considered for use with either of the longer boom samplers described. Examples of such mechanisms are discussed in Section II.A.1.f. With regard to imaging support for sampling operations with longer booms, the baseline '75 Viking lander imaging system would provide satisfactory resolution (0.6 milliradian) of sampling sites up to 10 m from the lander.

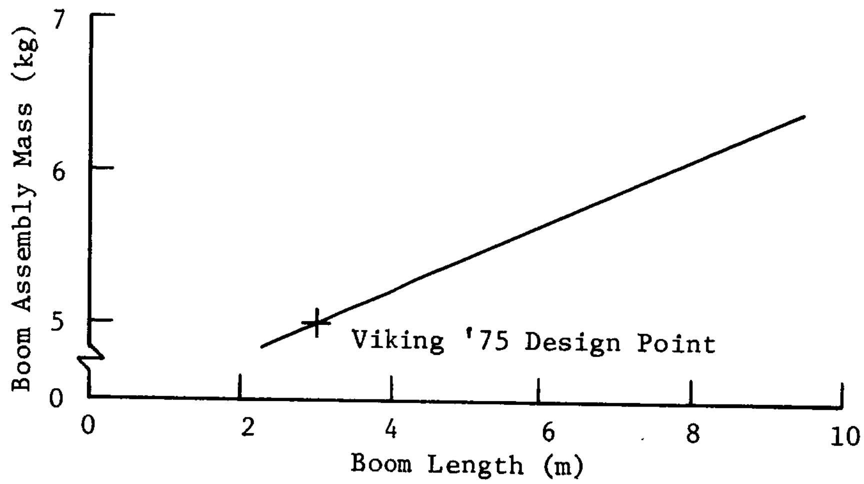


Figure II-3 Mass vs Length for Lengthened Baseline Viking '75 Sampler Boom

b. Mortar Samplers - Martin Marietta earlier investigated a mortar sampler concept of the type shown in Figures II-4 and -5. Compressed gas (nitrogen) is used to launch the collector tube along a selected azimuth. Elevation is fixed. A thin cable is payed out of an open-face reel in the rear of the mortar's launching tube. The collector tube is retrieved using this reel. A holed ball on the cable blocks the collector tube opening after the tube is drawn a short distance across the surface to collect a sample. When the collector tube enters the launch tube, the sample is dumped by gravity into a sample transfer mechanism for transport to the lander's processors and instruments. Total added mass for such a system would be approximately 10 kg (22 lb).

The concept illustrated could sample readily at ranges up to 100 m from the lander. Longer launch tubes and/or higher gas pressures could increase this range making it attractive in a

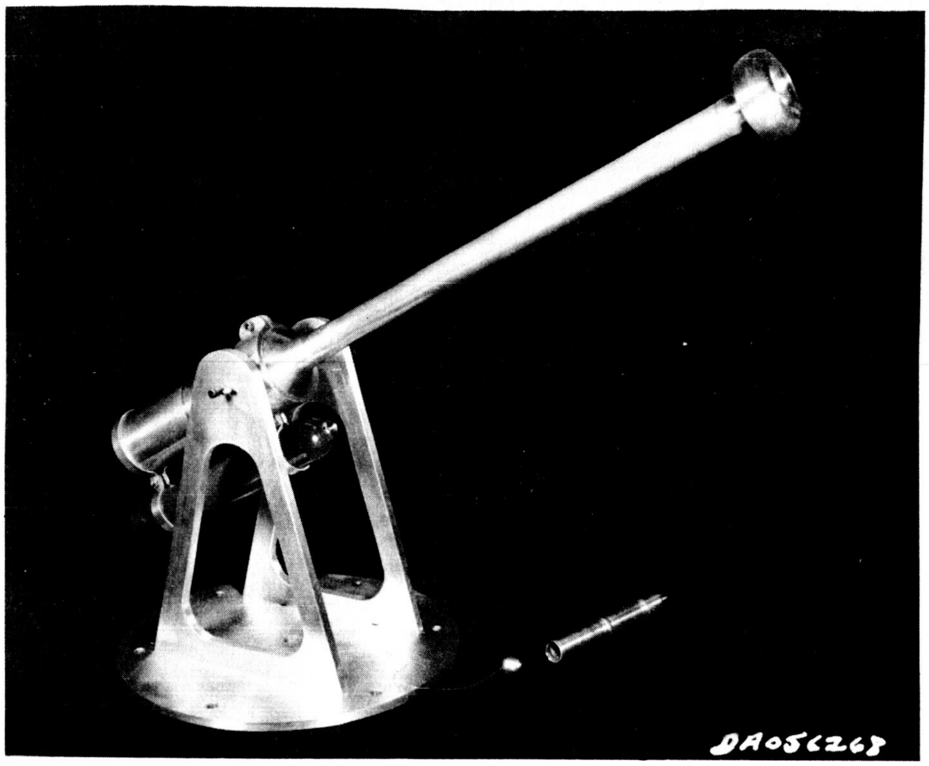


Figure II-4 Mortar Sampler

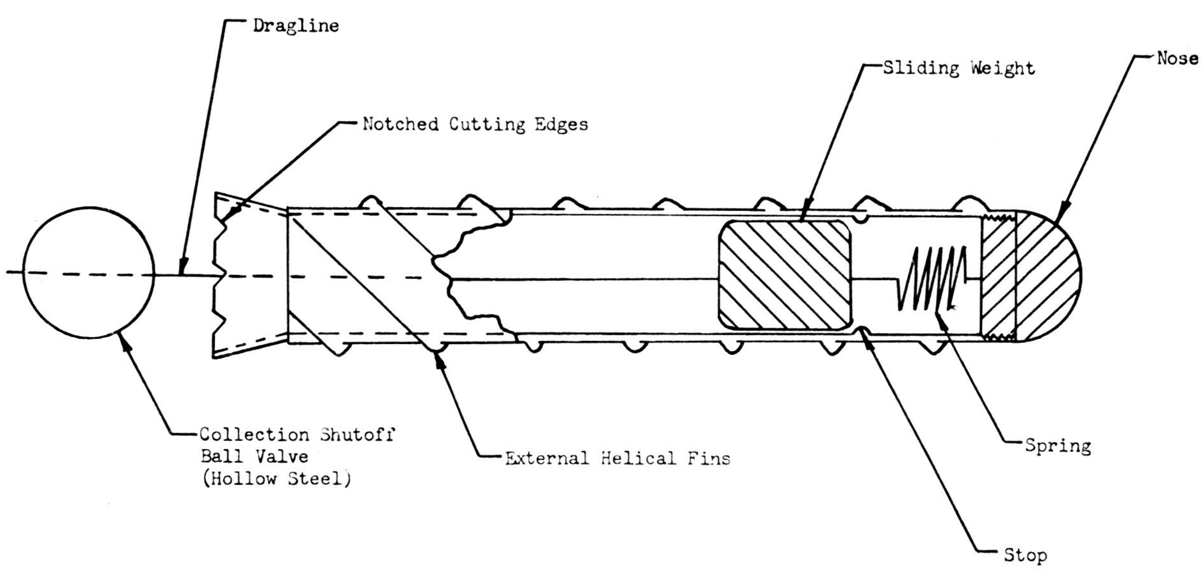


Figure II-5 Collector Tube

weight vs range comparison. The principal disadvantages of this system are its limited sampling aggressiveness and the possibility of collector hangup during retrieval.

c. Propulsive-hopping Lander - The concept of using residual or extra descent propellants to transport the lander from site to site has been suggested numerous times. It was proposed during the Surveyor Lunar Lander program but was rejected due to time and cost limitations. Under contract No. NAS1-10873, A Study of System Requirements for Phobos/Deimos Missions, Martin Marietta evaluated a propulsive-hopping lander concept. In the low gravity (.001 g) of the Martian moons, ballistic transfers can be effective if the capability is designed into the lander from the start. However, wheeled mobility was selected as a better alternative due to its controllability and the fact that the wheeled lander could traverse rougher surfaces than a reflyable lander could land upon safely.

During this study, discussions were held with Viking '75 lander systems design personnel to assess the feasibility and practicality of reflying the Viking lander. While the concept is feasible, it is not practical due to the level of modifications required on the lander. These modifications include:

- make landing legs and shock absorbers reuseable
- redesign the inertial reference unit for long life (it currently survives 5 minutes after landing)
- make the terminal descent and landing radar shock resistant and less vulnerable to destruction by surface objects
- add thermal control to the lander pyrotechnic control assembly
- replace one-shot propulsion valves with solenoids
- provide heating to keep external hydrazine lines from freezing up
- provide reuseable stowage and deployment mechanisms for the sampler boom, S-Band antenna, and meteorology boom.

d. Wheeled Lander Mobility - Two options were considered in this category: 1) adding three powered wheels to the lander to make the lander capable of cross-country travel and 2) adding two wheels to one side of the lander so that it can pivot about the leg on the other side of the lander. With regard to the first option (fully mobile lander), reliable mobility across soft, wind-deposited materials as are expected on Mars requires surface pressures (weight divided by wheel contact area) of less than 6900 N/m^2 (1 psi) and are preferably 3500 N/m^2 (0.5 psi). The Viking lander's weight on Mars is approximately 2250 N. Therefore the surface contact area, per wheel, should be 0.109 to 0.218 m^2. Using 0.164 m^2 as an average, the wheels would have to be approximately 0.3 m wide and have a radius of 0.5 m. Figure II-6 illustrates wheels of this size with the Viking lander. Also shown is one wheel superimposed (dotted lines) in the area of one of the footpads. It can be readily seen that wheels of this size cannot be stowed at the required corner positions without making major modifications to the entry and lander system.

The second wheeled lander option (pivoting lander) was considered in greater detail due to greater practicality. As shown in Figures II-7 and -8, two wheels are mounted on a deployment mechanism on the science side of the lander. Since each wheel must support only ¼ of the lander's weight and long-range, efficient mobility is not required, smaller wheels can be used than on the mobile lander described previously. Through rotation (3^{o} per minute with 8 watts of input power), the surface area accessible to the lander's baseline Viking '75 surface sampler is expanded by a factor of eight. Additionally, a 1 m rotary-percussive drill, deployed vertically between the wheels, will be able to sample at selected points along a 19 m

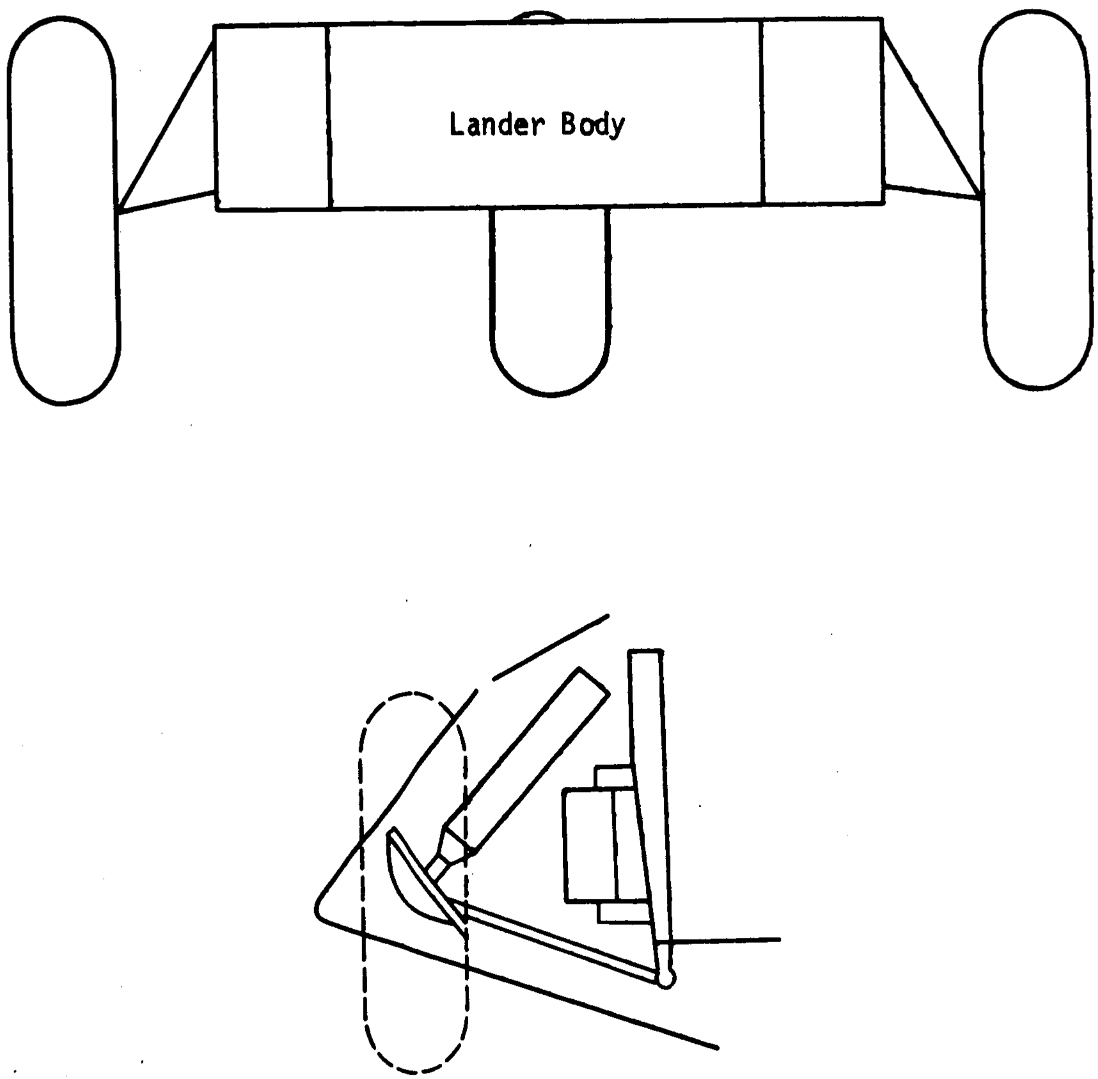


Figure II-6 Mobile Lander Wheels

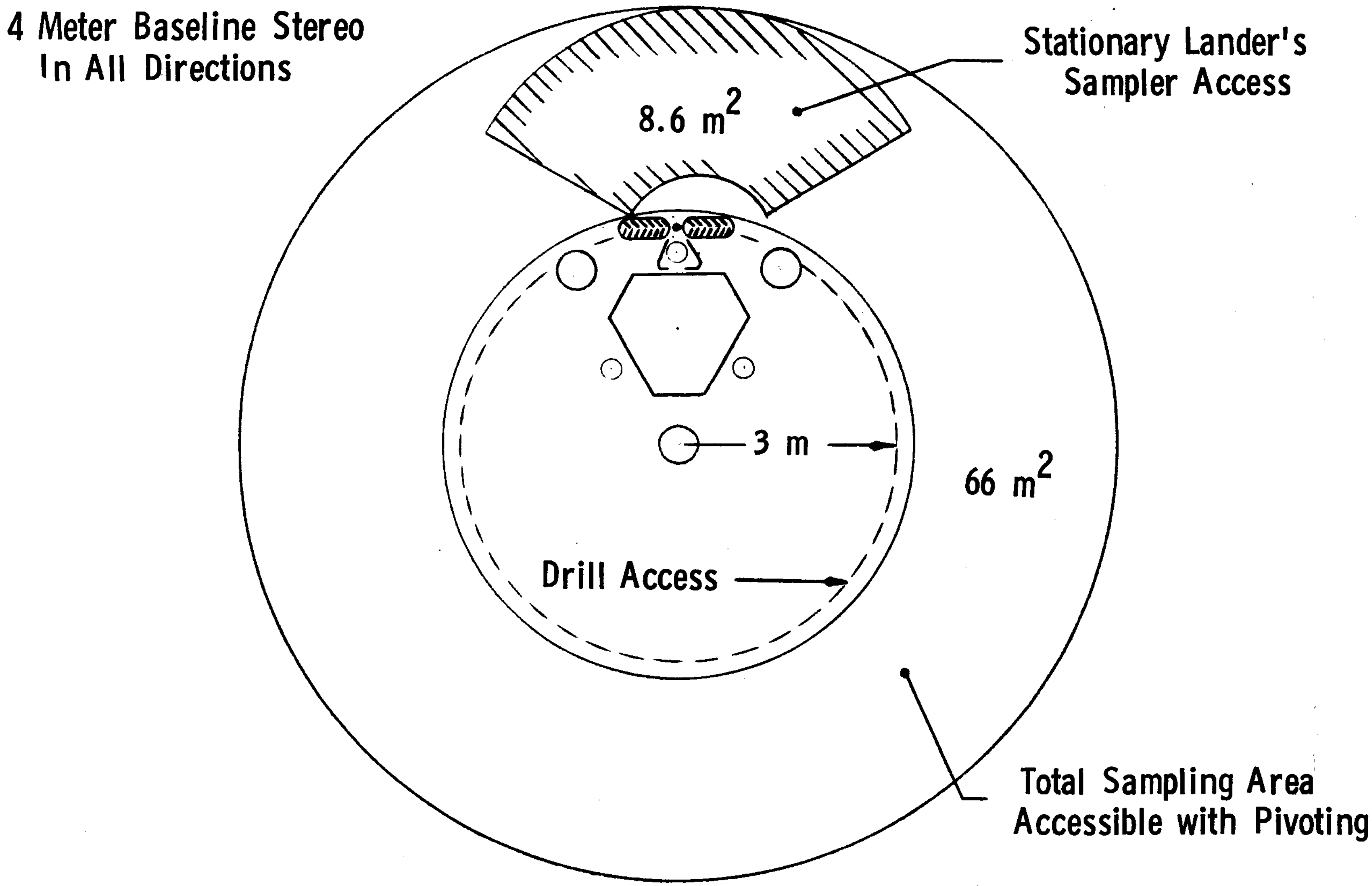


Figure II-7 Pivoting Advanced Lander - Science Enhancement

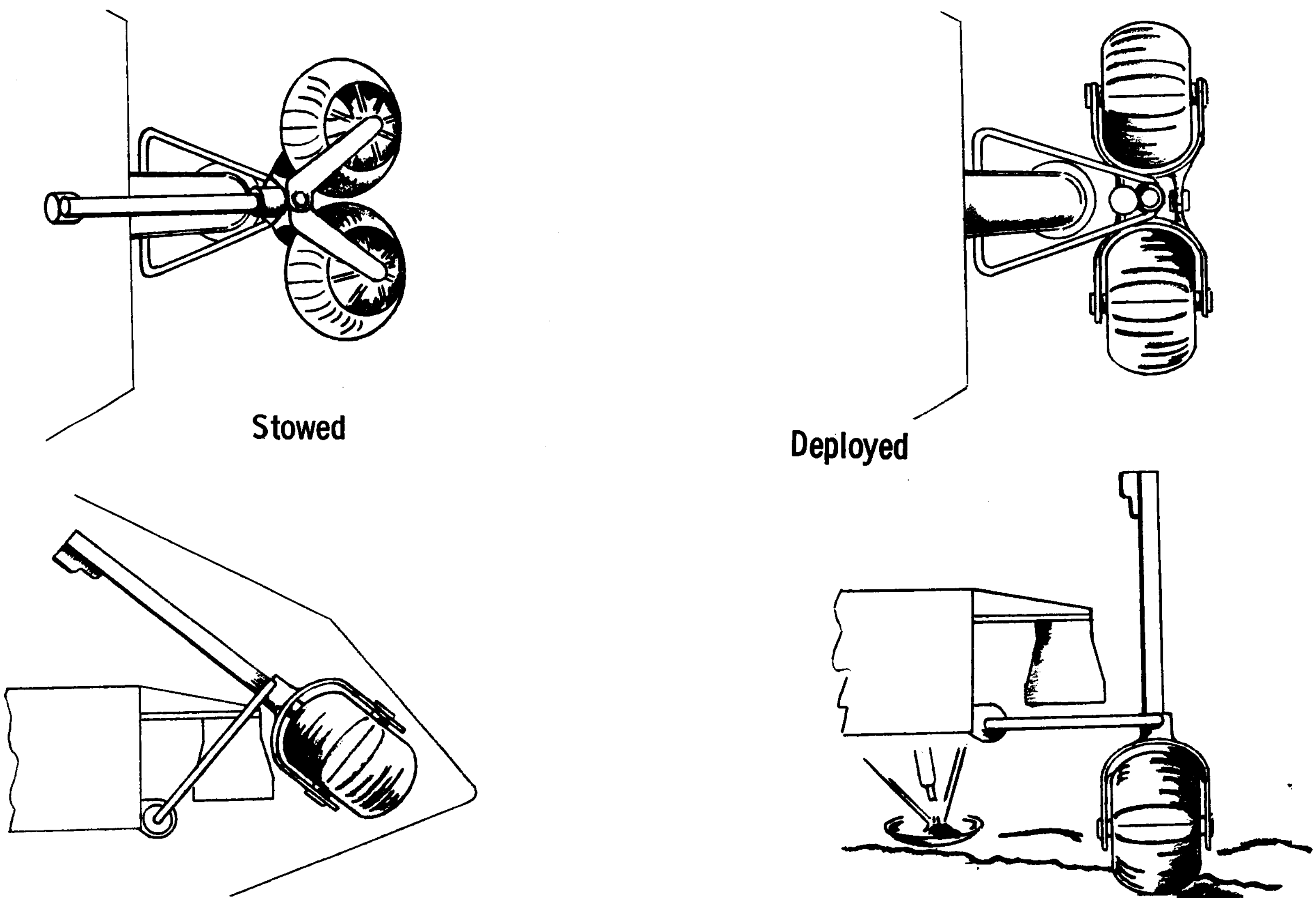


Figure II-8 Pivoting Advanced Lander - Stowage/Deployment circumference path. Autonomous controls must be provided for the mobility subsystem in order to achieve precisely controlled rotations, for the high-gain antenna pointing system whose commanded angles must be adjusted following the lander body motions, and for the rotary-percussive drill whose feed rate must be adjusted in real-time to keep drilling loads within safe margins.

Lander imagery would profit significantly from its ability to perform 4 m baseline stereo imagery in all directions during one full rotation of the lander.

Additional benefits may be derived by adapting to local prevailing winds. Such benefits could come from pointing meteorology instruments into the wind, rotating the lander periodically to change wind flow and dust accumulation patterns, or rotating the lander to elevate its science side on top of accumulating wind blown materials.

Analyses indicate this concept would add 60 kg to the landed system mass.

e. Drill Samplers - Reference 3 describes a study performed by Martin Marietta to evaluate a 15 cm long drill sampler as a backup sampler for Viking '75. The 1 cm diameter rotary-percussive drill test hardware is shown in Figure II-9. The no-load power consumption of this unit is approximately 22 watts. In drilling in particulate materials (lunar nominal), power consumption increases to 33.5 watts with an average of 15 watt-minutes required for each cc of sample collected. In consolidated materials (firebrick), power consumption increases to 56 watts and 20 watt-minutes are required to collect each cc of sample. Power levels can be reduced by slowing the drill operation but watt-minutes per cc can be expected to remain in the ranges indicated. The test unit's weight was 2 kg and 80% of

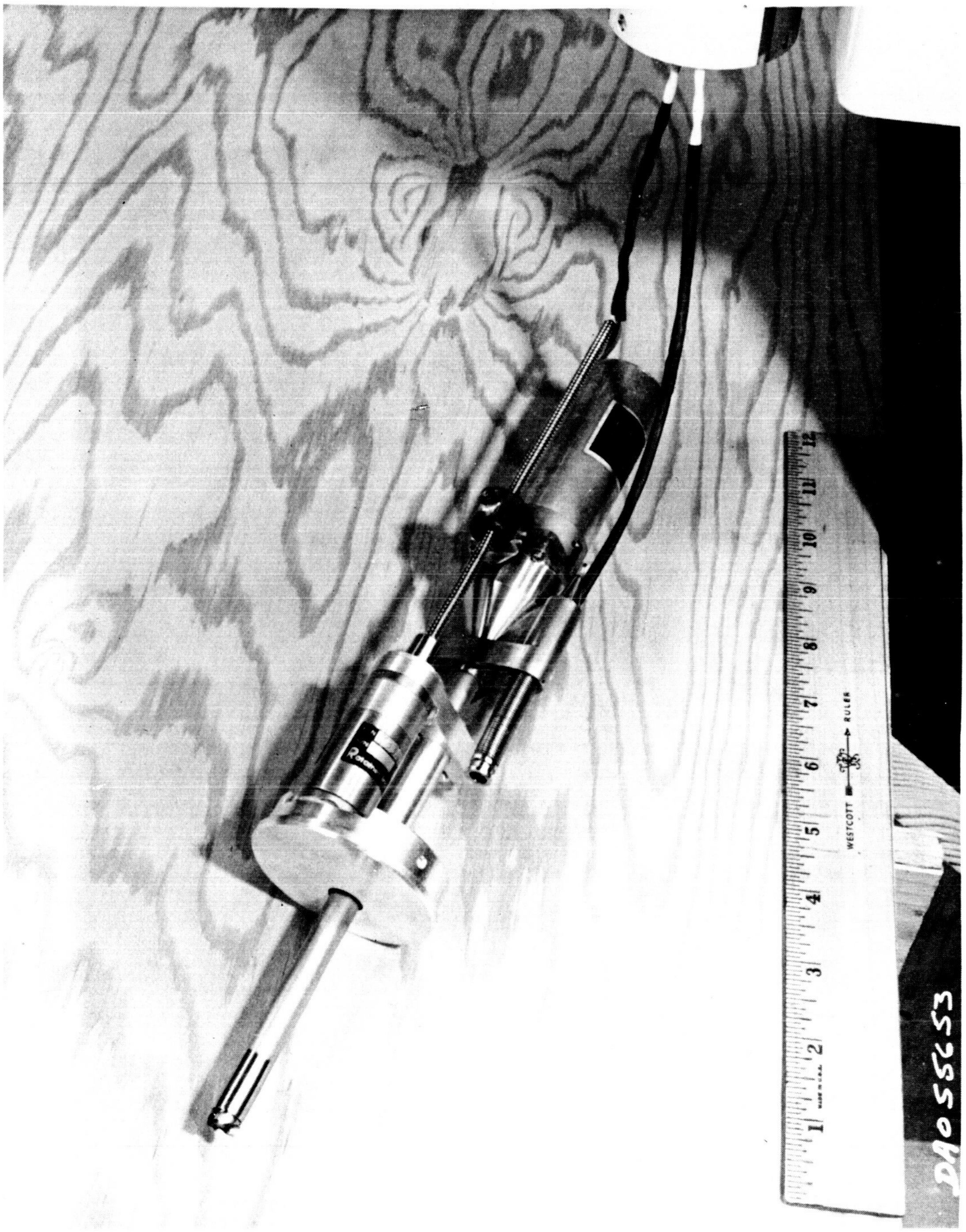


Figure II-9 Drill Sampler

the collected particles were smaller than 300 microns.

MMC is currently funding additional development work on a 1-meter long, 1 cm diameter, rotary-percussive sampling drill which operates in the same manner as the 15 cm drill described above. Predicted data for this drill indicate that it can be used satisfactorily on either a fixed lander or a rover. Such a drill is included where shown in the pivoting advanced lander (Figures II-7 and -8) or it could be mounted vertically on the side of a fixed lander.

f. Accessories for Sampling Booms - During evaluations of alternative concepts for sample acquisition on Viking '75, MMC fabricated and tested several of the most promising options. Table II-1 gives comparative performance data from these tests. Since the rotary-percussive drill was the only option capable of handling all surface material models and its power requirements were the most favorable, more comprehensive tests were conducted with the drill. The results of these tests and a description of the equipment used is given in Table II-2.

From these tests (all options) it is apparent that several sampling mechanisms could be built into, or made available to, a sampler boom (baseline or wheeled). While the drill is the best general-purpose sampler, others should also be considered for special applications. As examples, a rotary-brush sampler can collect samples from a thin, wind-deposited layer over bedrock, and a chipper can provide larger pieces from rock outcroppings. Neither of these examples is within the capability of a drill sampler.

Table II-1 Alternate Sampler Test Data

Normalized Power Requirement (P) (Watt-min/cc) and Sampling Rate (R) (cc/min)

Sampler	Particulate P	Particulate R	Firebrick P	Firebrick R	Vesicular Basalt P	Vesicular Basalt R
Rotary Percussive Drill (1.9 cm)	2.0	200	2.8	132	49	8
Electric Chipper	N/A	N/A	27.0		200	0.1
Pneumatic Chipper	N/A	N/A	---	3-5	---	1.0
Optimum Abrader	N/A	N/A	33.0	4.5	300	0.5
Rotary Brush	10	6-10	N/A	N/A	0	N/A
Rotating Auger	20	6-8	N/A	N/A	N/A	N/A

N/A = Not Applicable

Table II-2 Additional Drill Sampler Data

Surface Model	Sampling Rate (cc/min)*	Power Requirement (watt-min/cc)	Sample ΔT (^{o}C)
Lunar Nominal	184	2.2	3.3
Dune Sand	77	5.3	4.4
Loess	55	7.2	5.5
Firebrick	127	7.4	5.5
Vesicular Basalt	14	56.0	11.0

* Samples transported to a point 76.2 cm above acquisition surface by the rotating drill bit helix.

Equipment:

(1) Black & Decker 814 Hammer Gun - 115V AC/DC, 3.5 Amps, 1600 rpm, 1.8 kg mass
- 16,500 bpm, 0.0813 Nn/Blow

(2) Tungsten-Carbide Tipped Drill - 91.4 cm length x 1.9 cm cutting diameter.
- Single lead flute, 3.5 pitch, helix 3.175 mm wide x 1.59 mm depth

(3) Outer Non-rotating Case - 76.2 cm length x 1.587 cm I.D. x 1.746 cm O.D.

2. Selected Advanced Lander Concept

Using the results of the analyses just described and the science payload analyses described in Chapter IV, the advanced lander concept illustrated in Figures II-10 and II-11 was selected. This concept meets the groundrules specified initially in that it will be capable of performing more advanced and detailed scientific investigations than the Viking '75 mission and it will keep modifications to non-science related systems to a minimum. The full science payload and its adaptive functions are described in Chapter IV.

A landed weight summary by subsystem is shown in Table II-3. The current Viking '75 subsystem weights are shown for comparison. The additional landed mass of 42.7 kg requires an additional 14 kg of terminal descent propellant. There are no additional modifications required on the basic lander or aeroshell structure as a result of the increased landed mass.

A Planetary Landing Site Selection System (PLSSS) installed as shown in Figure II-10 is proposed for use on all of the Mars landed system concepts considered. As illustrated in Figure II-12, the PLSSS is an autonomous system which, during the powered descent phase, scans the predicted landing area with a visual sensor, identifies the sub-area containing the lowest density of visually-observable irregularities, and provides inputs to the lander's guidance system to bias the powered descent trajectory to the desired sub-area. For this function, the visual sensor's 60° field-of-view (FOV) is electronically restricted to the 12° containing the predicted impact area and adjacent areas that can be reached through trajectory biasing. However, during the parachute phase and the powered descent phase, full 60° FOV images with resolution as shown below can be obtained

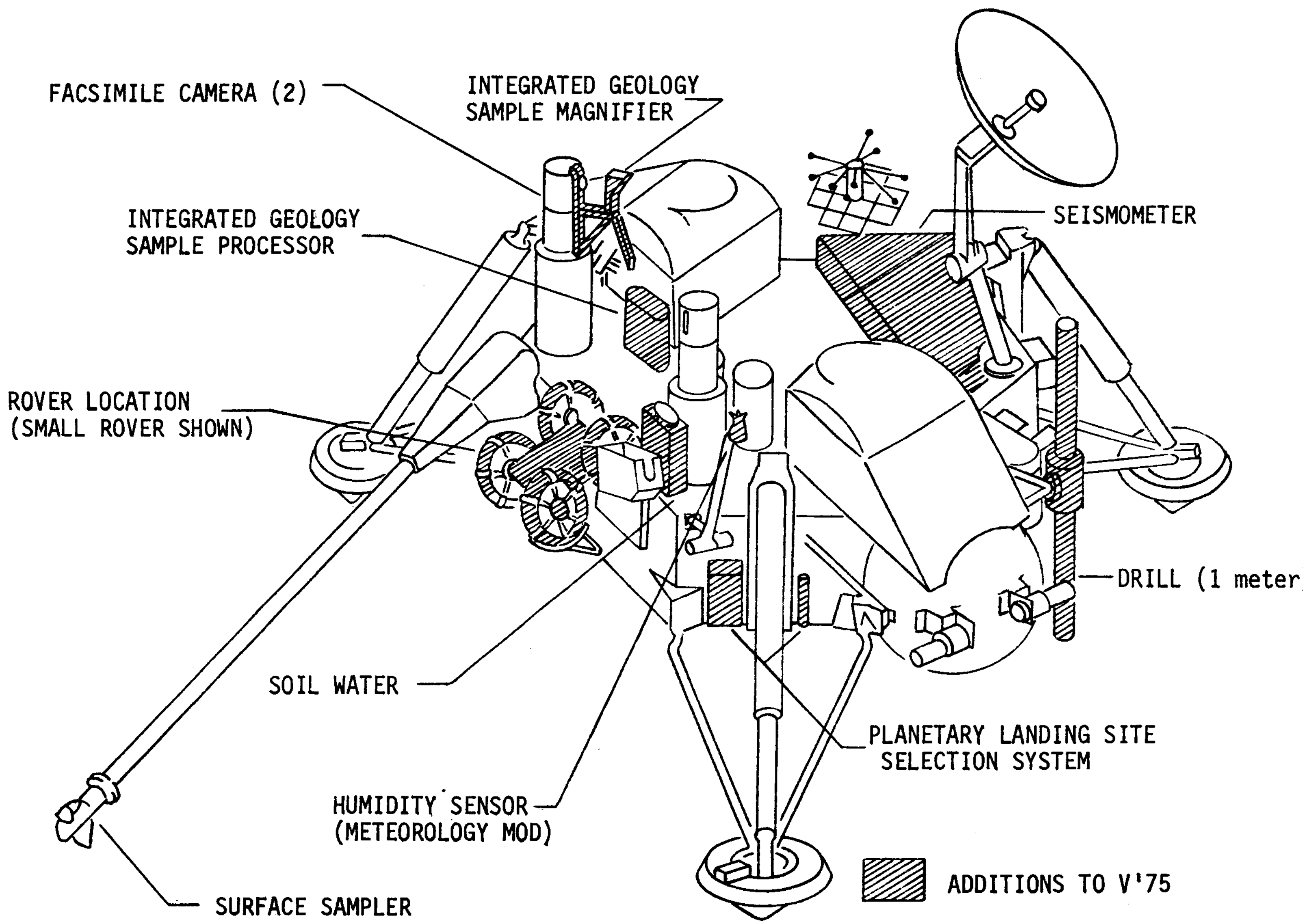


Figure II-10 Selected Advanced Lander Concept

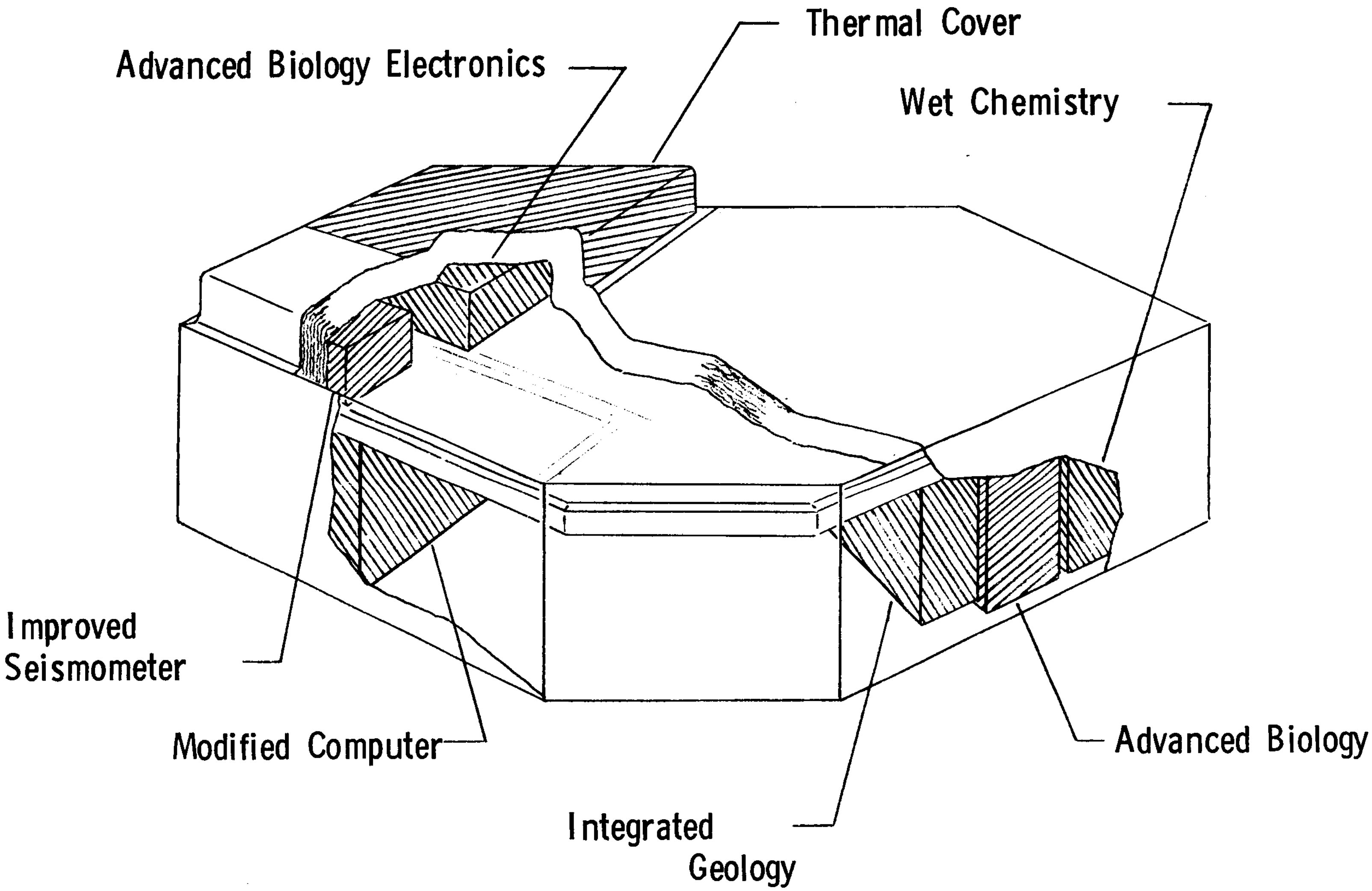


Figure II-11 Advanced Lander Internal Modifications

Table II-3 Advanced Lander System Mass

Subsystem	Current Viking '75	Δ Wt	Advanced Lander
Structures	106.6	+ 8.6	115.2
Propulsion	49.9		49.9
Pyro	11.8		11.8
T/C	28.1	+ 0.9	29.0
Power	98.4		98.4
Telemetry	19.5		19.5
G&C	62.7	+ 2.3	65.0
Comm	34.0		34.0
Harness	24.9	+ 4.5	29.4
Science	86.2	+26.4	112.6
Reserve	27.1		27.1
Res. Prop.	16.8		16.8
Press.	9.5		9.5
Landed Weight	575.5	+42.7	618.2 kg

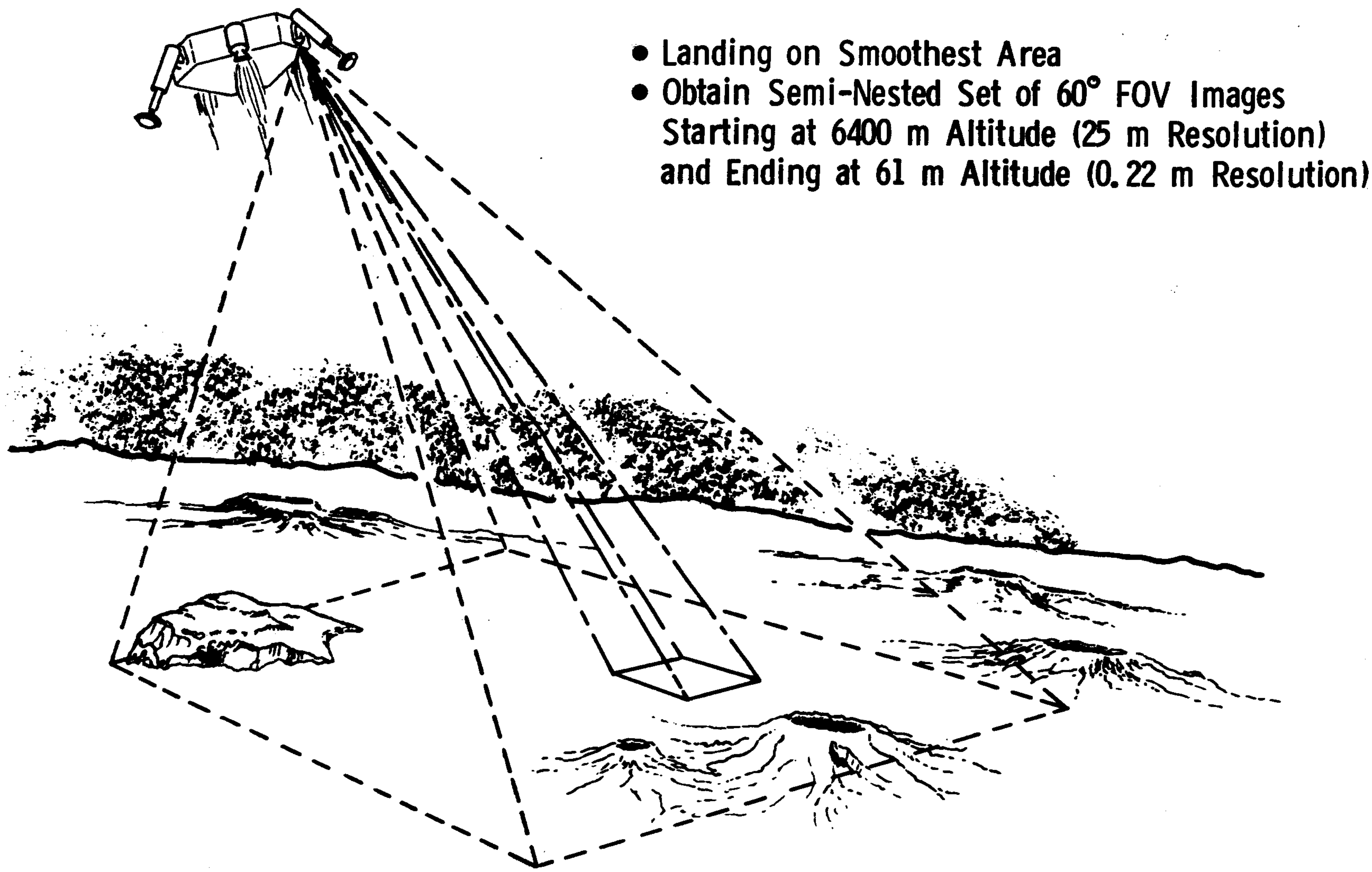


Figure II-12 Planetary Landing Site Selection System (PLSSS) periodically and recorded. These images will be of great value in locating the landing site in orbiter imagery and in planning post-landed rover traverses to areas not visible to the lander due to terrain obscurations.

B. LANDER WITH SMALL ROVER

The second of the three Mars landed system concepts considered was a lander with a small rover. The primary function of the small rover is to gather interesting surface samples and transport them to the lander for detailed analysis by the lander's instruments. Guidelines for the small rover specified that it should have an operating radius of at least 50 meters from the lander and that its integration into the lander system would require only minor modifications to the Viking '75 lander design.

Martin Marietta has been investigating a small rover concept for over two years. Initiated first under the Viking Program (backup sampling system analyses, Ref. 4), the concept was later carried to the functional model stage illustrated in Figure II-13. Such a concept is representative of the small rover specified for this study and, accordingly, the concept was defined in greater detail to permit adaptive mode analyses.

A wide range of capabilities can be incorporated into a small rover. For this reason, two small rover concepts were defined. Their stowed location on an advanced lander is shown in Figure II-10.

The first of the two concepts is the standard small rover illustrated in Figure II-14. This tethered rover would be capable of sampling within a 100 meter radius of the lander. The 0.65 m long by 0.4 m wide vehicle would add approximately 24 kg to the 618 kg mass of the advanced lander. The mass breakdown for the advanced lander with the standard small rover is shown in Table II-4. The rover would receive its power and commands via a cable from the lander. The Viking '75 surface sampler control assembly, enlarged 20% to accommodate the rover

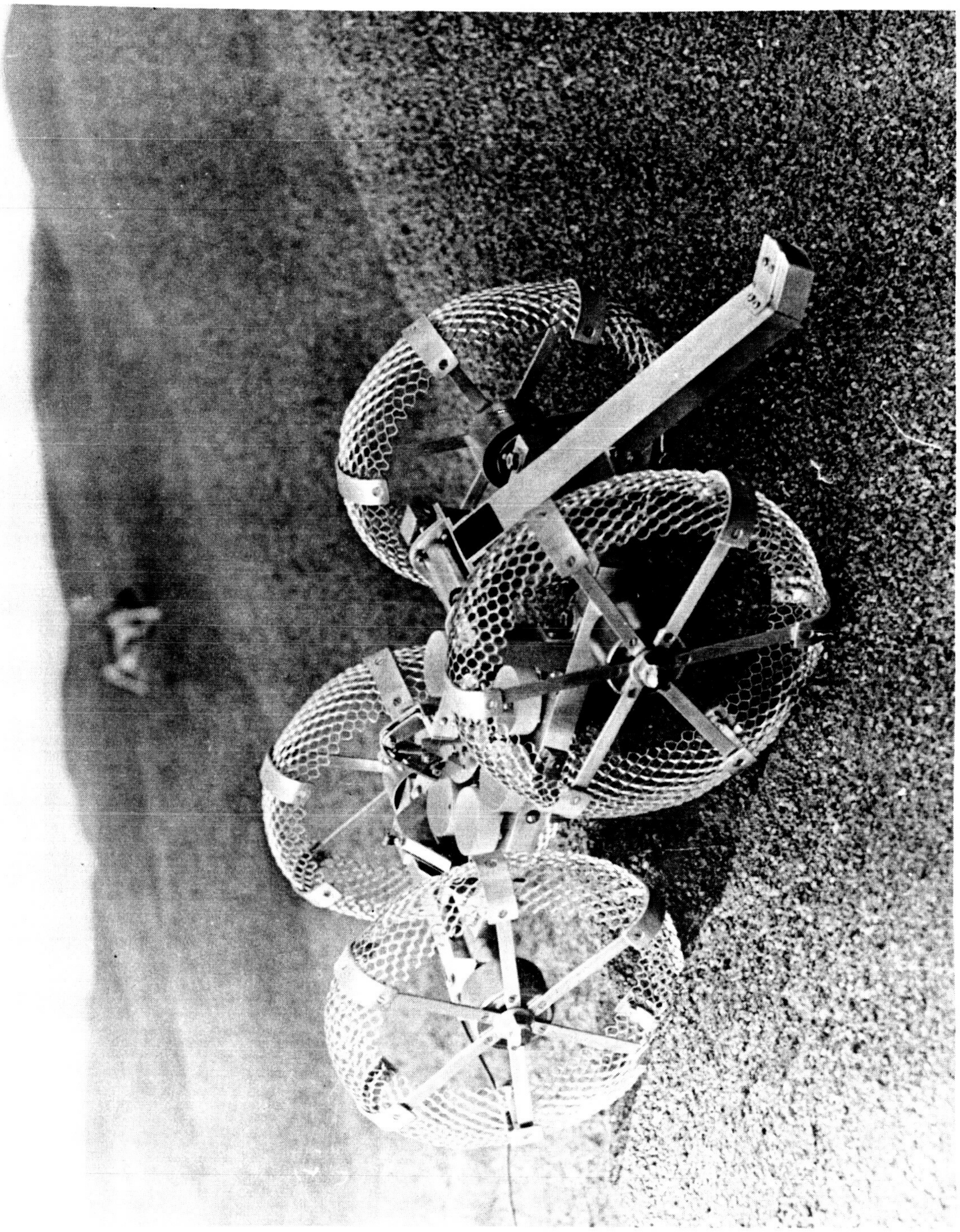


Figure II-13 MMC Roving Sampler and Analyzer

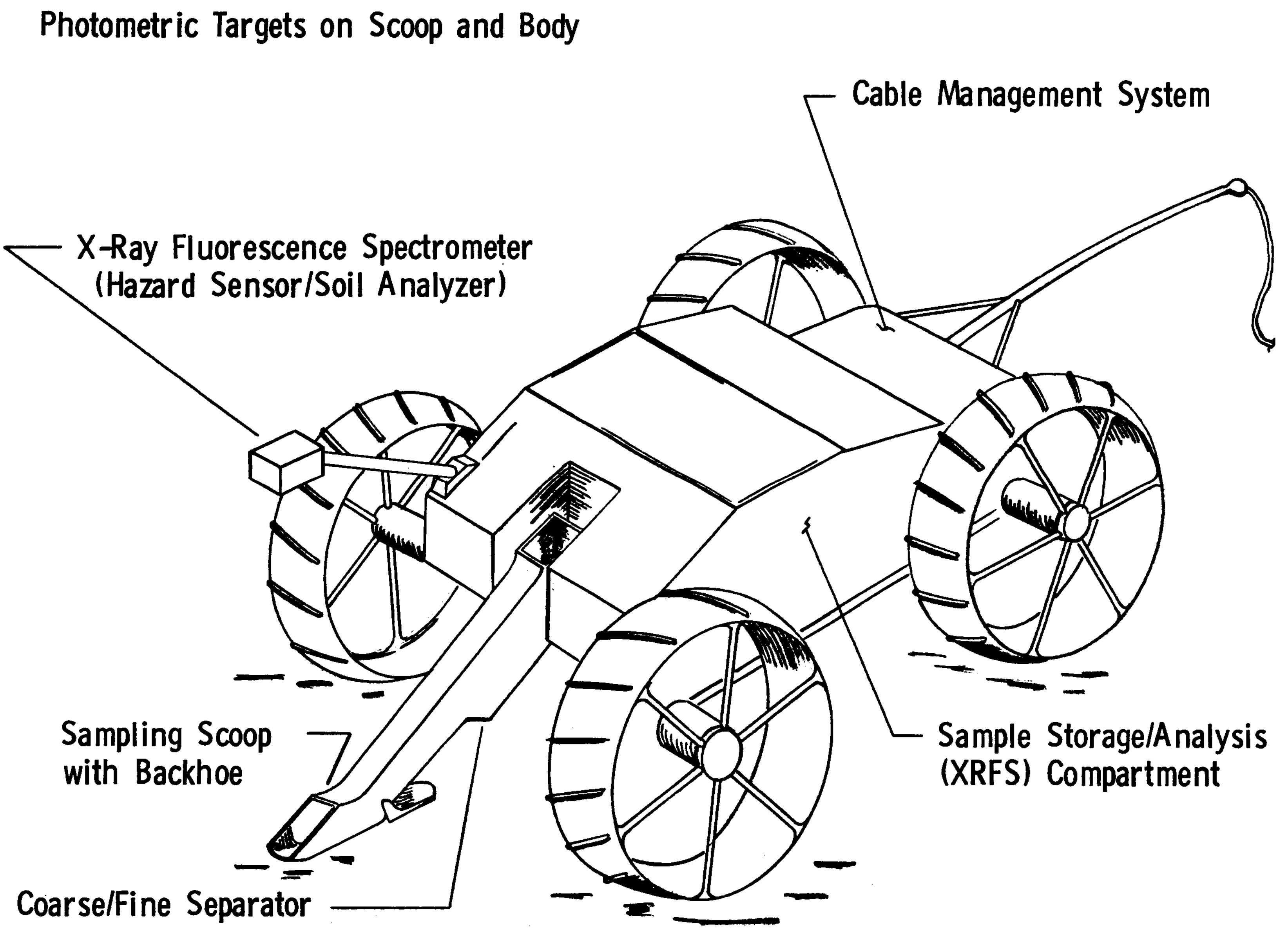


Figure II-14 Standard Small Rover

Table II-4 Mass Breakdown--Advanced Lander with Standard Small Rover

Subsystem	Current Viking '75	ΔWt	Advanced Lander with Standard Small Rover
Structures	106.6	+11.8	118.4
Propulsion	49.9		49.9
Pyro	11.8		11.8
Thermal Control	28.1	+ 0.9	29.0
Power	98.4		98.4
Telemetry	19.5		19.5
G&C	62.7	+ 2.3	65.0
Comm	34.0		34.0
Harness	24.9	+ 4.5	29.4
Science	86.2	+47.3	133.5
Reserve	27.1		27.1
Res. Prop.	16.8		16.8
Press.	9.5		9.5
Landed Weight	575.5	+66.8	642.3 kg

functions, would operate the rover under the direction of the lander's GCSC. The rover would collect multiple samples, eliminate redundant ones if desired based on x-ray fluorescence spectrometer (XRFS) analyses, and return the retained samples to the lander for processing and detailed analysis.

The second small rover concept (deluxe) is shown in Figure II-15. It consists of the standard version with the labeled subsystems added, thereby providing it with significantly enhanced science capability. As shown in Table II-5, this vehicle would add approximately 35 kg to a 618 kg advanced lander, giving a total added mass, compared to Viking '75, of 77.6 kg.

Parameters for both the standard and deluxe small rover are given in Figure II-16. The primary differences are in data rate and science volume, higher rates and volumes being required on the deluxe configuration due to its added science payload. Typical performance figures for both small rover configurations are given in Table II-6.

Small rover sampling will employ a scoop deployed at the end of a stiff arm. Samples will be acquired by lowering the scoop to the surface and then driving the rover forward. After a fixed distance is traveled, the scoop is elevated. If the entire sample is wanted, the arm is rotated until the sample is deposited in a storage tray. If only those particles greater than 0.5 cm diameter are wanted, the arm is elevated to $+45^{o}$ then down below horizontal to dump the fines overboard through a screen prior to depositing the sample is a storage tray.

Once the sample is in the tray, it will be analyzed using the XRFS to determine if a sample has been acquired, and if so, its elemental composition. If the sample does not need to be returned to the lander, the tray will be rotated to dump the sample overboard.

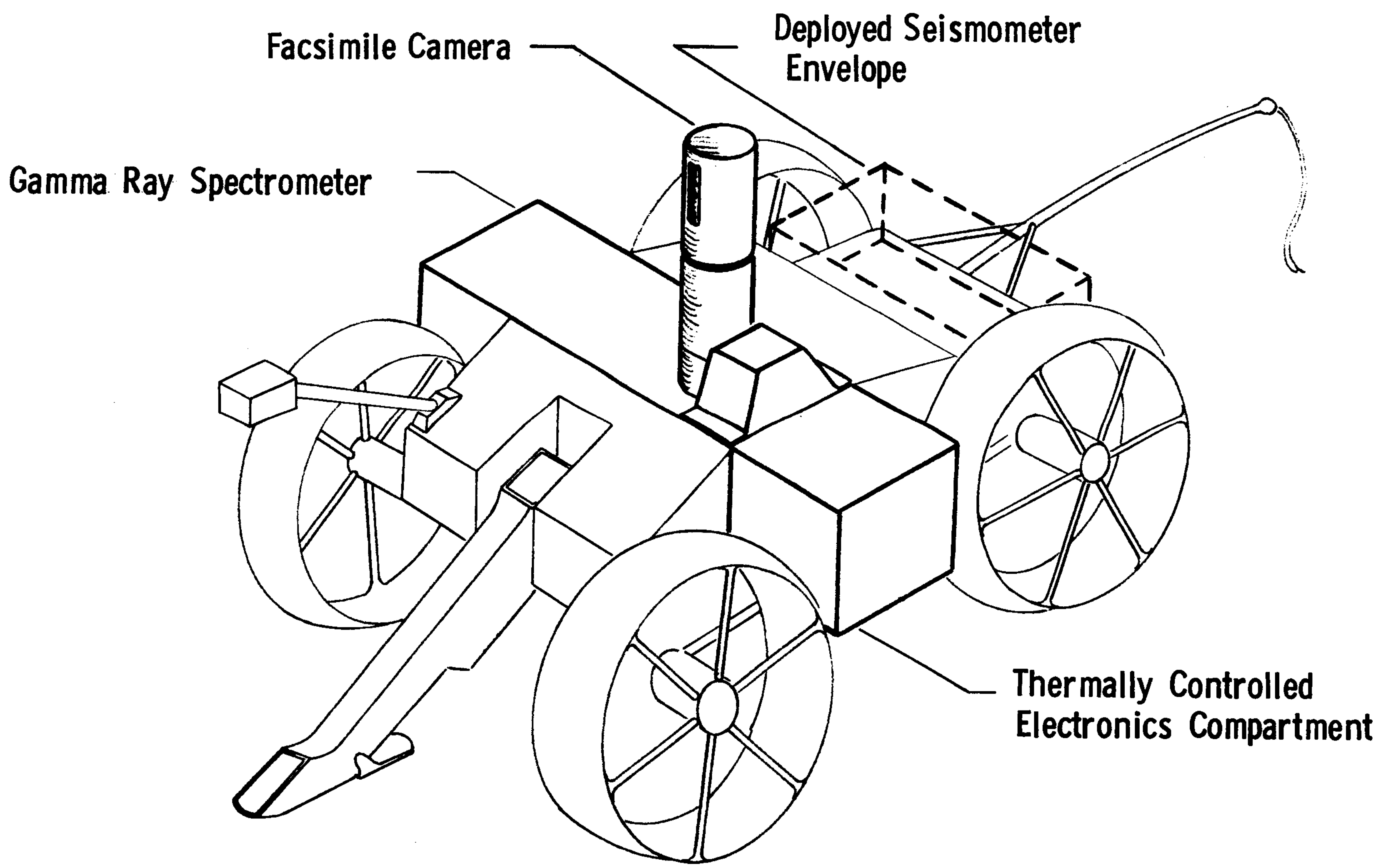
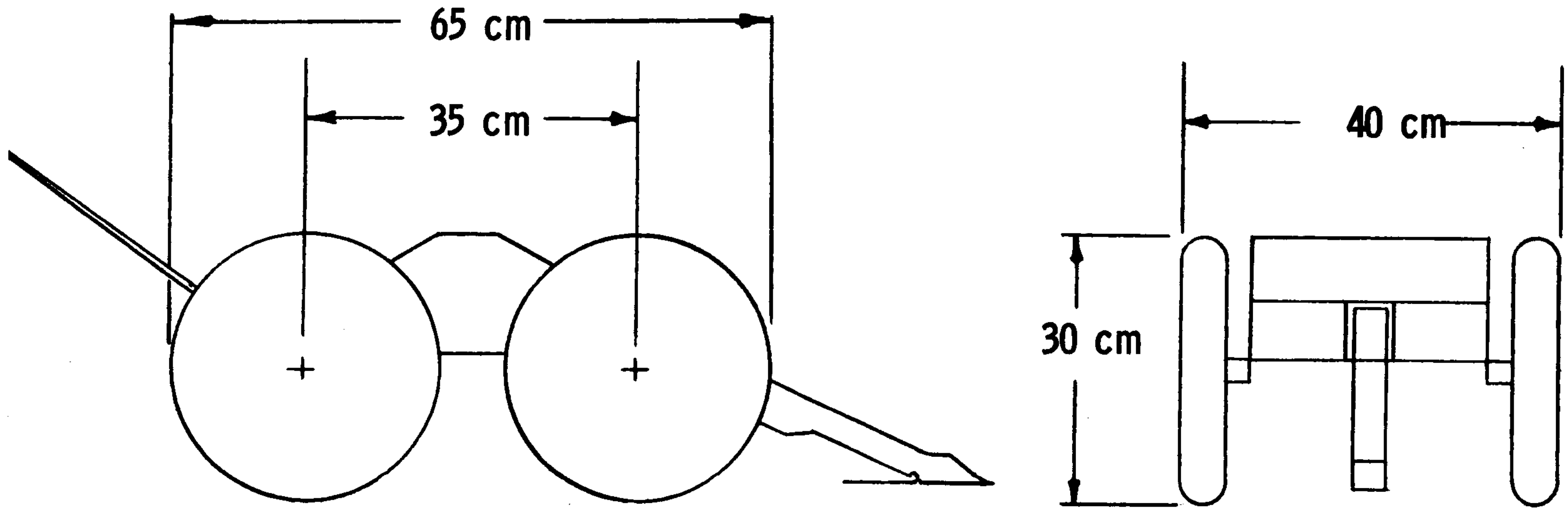


Figure II-15 Deluxe Small Rover

Table II-5 Mass Breakdown--Advanced Lander with Deluxe Small Rover

Subsystem	Current Viking '75	Δ Wt	Advanced Lander with Deluxe Small Rover
Structures	106.6	+12.7	119.3
Propulsion	49.9		49.9
Pyro	11.8		11.8
Thermal Control	28.1	+ 0.9	29.0
Power	98.4		98.4
Telemetry	19.5		19.5
G&C	62.7	+ 2.3	65.0
Comm	34.0		34.0
Harness	24.9	+ 4.5	29.4
Science	86.2	+57.2	143.4
Reserve	27.1		27.1
Res. Prop.	16.8		16.8
Press.	9.5		9.5
Landed Weight	575.5	+77.6	653.1 kg



SAMPLE CAPACITY

8 Segregated Samples
30 cc/Sample (max)

POWER REQUIREMENT

Standard - 10 w Peak
Deluxe - 15 w Peak

DATA RATE

Standard - 500 bps
Deluxe - 16 kbps

SCIENCE VOLUME

Standard - 9.3×10^3 cc (.33 ft^3)
Deluxe - 1.8×10^4 cc (.66 ft^3)

Figure II-16 Small Rover Design Parameters

Table II-6 Small Rover Performance Parameters

Range	50-100 m, 360^0
Nominal Operating Velocity	56 meter/hr
Power for Mobility	4 w @ 28 VDC
Roll Stability Limit	45^0
Pitch Stability Limit	45^0
Step Climbing Capability	10 cm (level surface, $\mu = 0.6$)
Crevice Spanning Capability	24 cm (level surface, $\mu = 0.6$)
Slope Climbing Capability	25^0-45^0 (surface composition limited)
Ground Clearance	12 cm
Command Word Length	10 bits ('75 Viking SSCA)
Traverse Segments	10 m @ 2 cm resolution
Turn Segments	360^0 @ 0.7^0 resolution

If a sample is wanted from below the immediate surface (as far as 10 cm down) the scoop will be deployed to the surface and the rover driven backward. A hoe on the bottom of the scoop will dig a trench. Once the trench is dug, the normal sampling mode will be followed. Typical sampling parameters for both small rovers are given in Table II-7.

Table II-7 Small Rover Sampling Parameters

Sampling Mode	Scoop Bulk Samples
Sampler Force Limit	17 newtons
Surface Cohesion Limit	3.5×10^4 newton/m^2
Slope Limit	-10^0 to $+90^0$ along longitudinal axis
Number of Samples per Sortie	8
Maximum Volume per Sample	16 cm^3
Screening (Optional)	Retain particles greater than 0.5 cm
Acquisition Depth	0-10 cm
Accessible Sampling Area	0.8×10^4 m^2 (50 m radius)
Sample Transfer	Dock with existing surface sampler, transfer samples individually

C. ADVANCED LANDER WITH MEDIUM ROVER

The third and final Mars landed system concept defined for use in the adaptive mode analyses was an advanced lander with a medium rover. Study groundrules specified that the medium rover would be able to make sorties to a distance of 1 km from the lander, would carry imagery and other appropriate science instruments, and would be able to make science-related decisions using onboard logic. More extensive lander modifications would be permitted than with the small rover but the essential character of the Viking '75 lander would be preserved. Further, the medium rover and the lander would have a communications link, but only the lander would have a telemetry link with Earth.

Such a medium rover is, by itself, a complex spacecraft and its detailed analysis and design was beyond both the scope and intent of the study. Accordingly, a variety of preliminary medium rover concepts were defined based on the constraints imposed by the lander. Preliminary analyses indicated that, if possible, the medium rover should be stowed in available volume within the Viking '75 entry system. The rationale for this constraint was that any redesign or rebuild of the Viking '75 lander to produce a new rover stowage volume of 0.5-1.0 m^3 would have an unacceptable cost impact. Therefore, to keep the medium rover concept both feasible and practical, analyses were conducted to define available volumes. The results of this analysis are shown in Figure II-17. Although a significant volume is available in this location in the Viking '75 system, there are two modifications which make the volume larger and more suitable for rover stowage. First, the surface sampler is stowed in a new position outboard of the cameras rather than between them. The tie-down post for stowage support must also

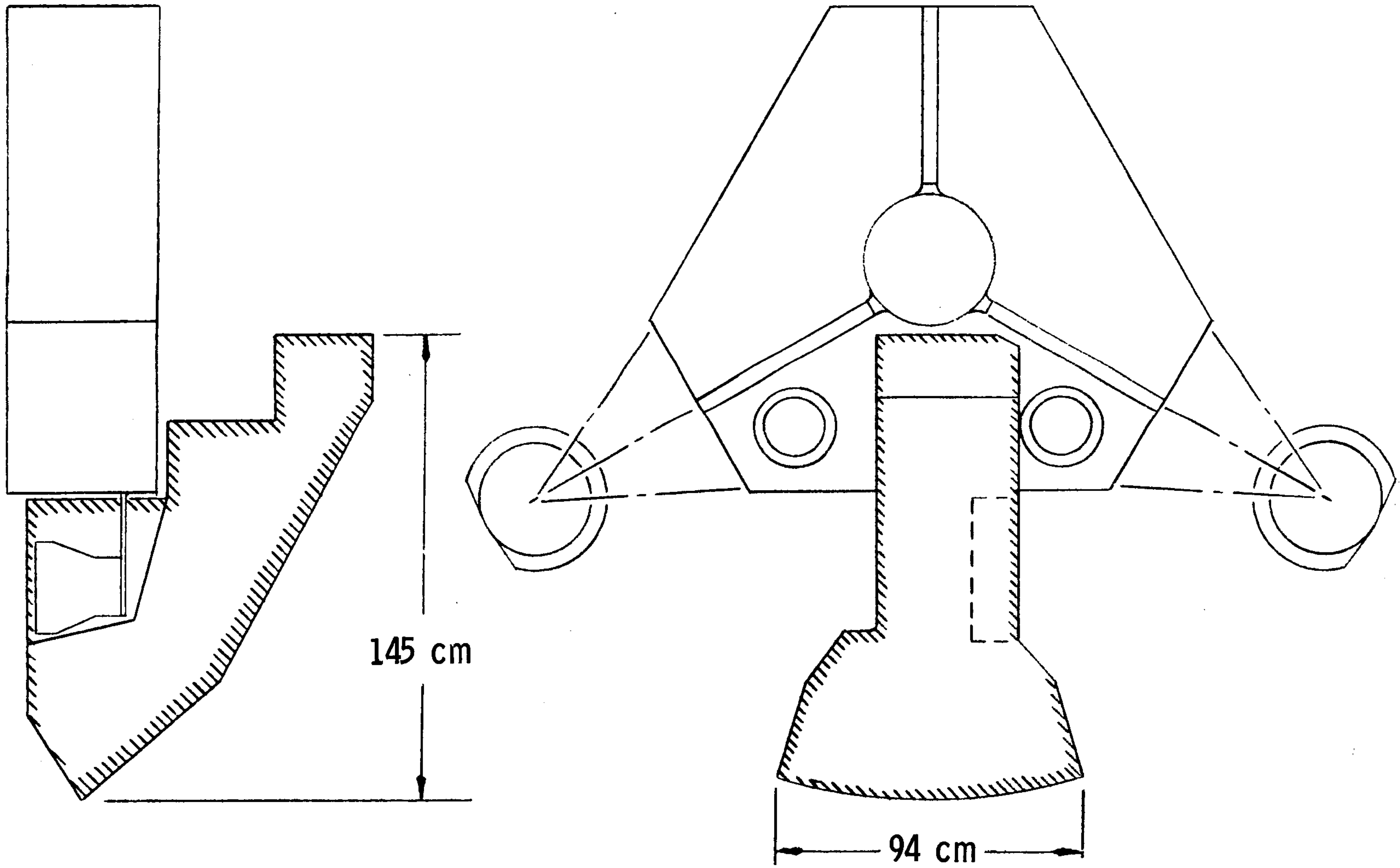


Figure II-17 Available Volume in Viking '75 Lander Capsule be moved to this new location. Second, a bulge is built into the basecover (entry capsule afterbody) within the bioshield envelope. The radius of curvature on this bulge will be smaller than on the baseline vehicle, and the heating rates will be higher in these areas during entry. Accordingly, the bulge will have to be sprayed with an 0.10-0.15 mm layer of ablative material or made of thin metal sheet. Both of these modifications are straightforward and require no new technology.

Given this available volume, several medium rover concepts were considered. Figure II-18 illustrates four candidate configurations to approximately equal scale. These 100 kg-class vehicles would be capable of traveling 1 km or more from the lander. All except the 6-wheeled vehicle can be folded and stowed in the available volume described previously. The 6-wheeled rover with 35 cm diameter wheels and 0.09 cubic meter body volume would have to be stowed on top of the lander in space made available by elevating the parachute mortar and truss assembly (major modifications). The 3-wheel unit has 50 cm diameter wheels and an 0.07 cubic meter body volume. The 4-wheel unit has 40 cm diameter wheels and an 0.07 cubic meter body volume. The 3-elastic-loop concept (Lockheed mobility subsystem) has 60 cm long loops and approximately 0.05 cubic meter body volume.

Each of these medium rover candidates could be equipped with the representative science payload shown in Table II-8 . The stereo imagery would use facsimile cameras approximately half the size of those on Viking '75. The "sieves" would provide initial screening of samples for inorganic and organic content. Samplers as shown would be a half size Viking '75 sampler and a 1 m rotary-percussive drill. Mechanisms for storing samples and transferring them to the lander complete this payload.

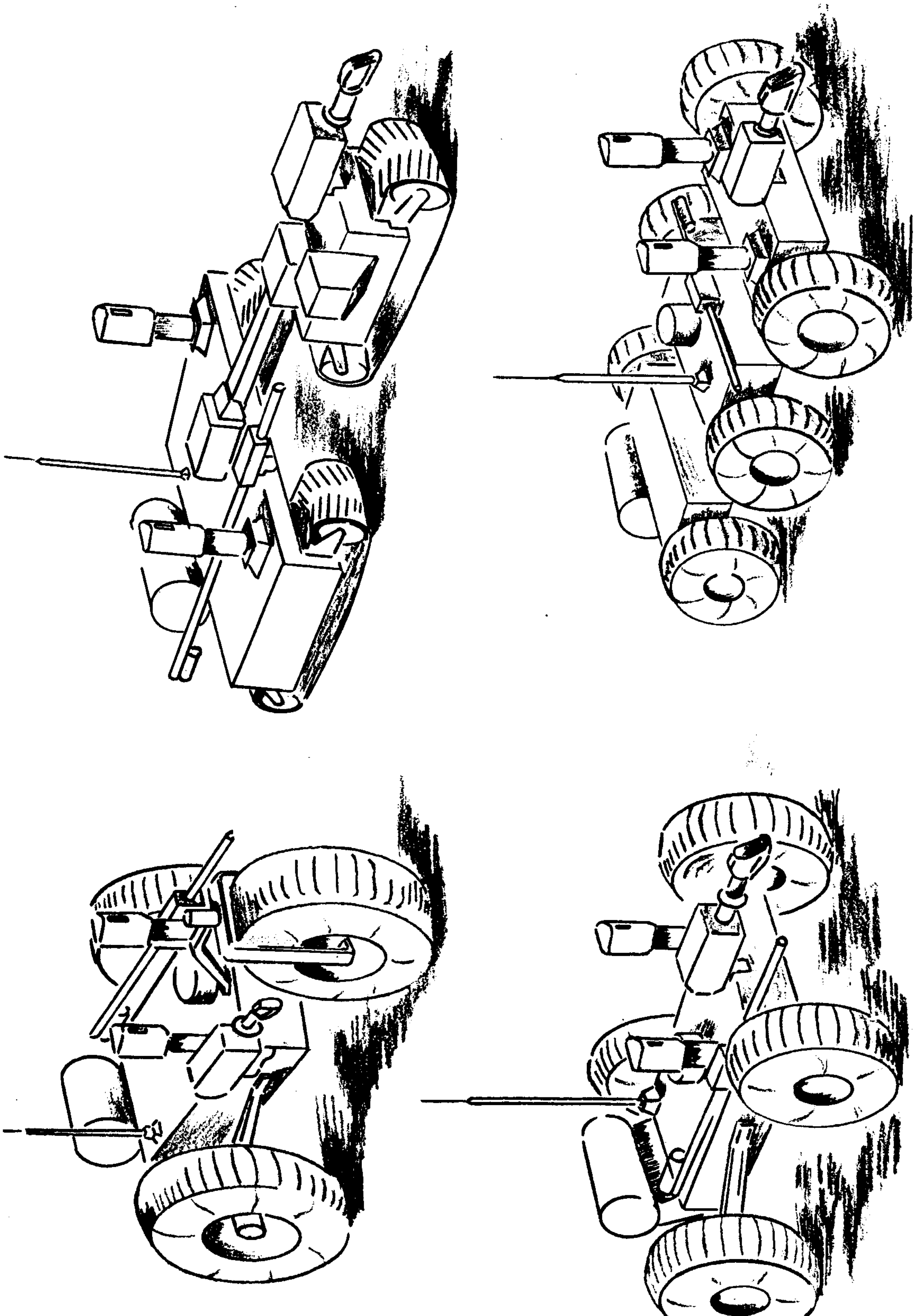


Figure II-18 Medium Rover Candidates

Table II-8 Typical Medium Rover Science Payload

Stereo Imagery - Normal, Telephoto, Quasi-Microscope

Sieves - Inorganic, Organic

Samplers - Scoop, Drill

Sample Storage and Transfer

Instruments That Could Be Deployed Away From Lander By Rover

- Active and/or Passive Seismometry Elements
- Gamma Ray Spectrometer
- Neutron Activator

Also listed are instruments suitable for deployment away from the lander by the rover. Both the gamma ray spectrometer and the neutron activator require separation from the lander's RTGs.

The four-wheeled concept was selected for additional analysis and its refined configuration and parameters are presented in Figures II-19 and -20. While this concept should not be construed as being either final or recommended, it is representative of the maximum size vehicle which could be transported with a Viking '75 system incorporating a practical level of modifications.

As shown in Table II-9, the landed mass of the advanced lander with this medium rover attached is approximately 754 kg. This represents an increase of 178 kg over the Viking '75.

The medium rover concept utilizes the lander's GCSC for executive control as described in Chapters IV and V. If the rover power supply is equipped with an RTG, the rover's sortie range will be limited primarily by the range of the rover-to-lander

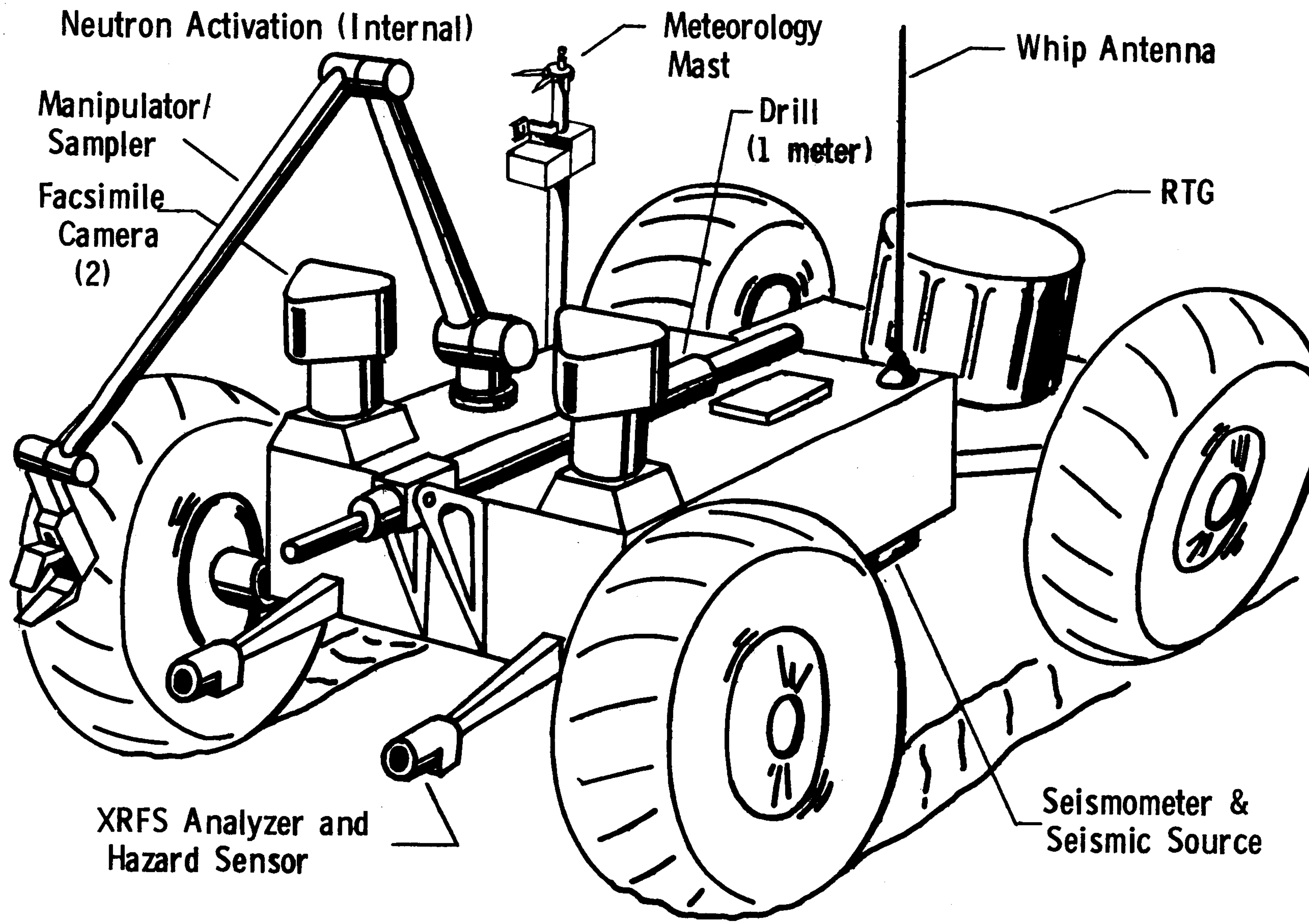
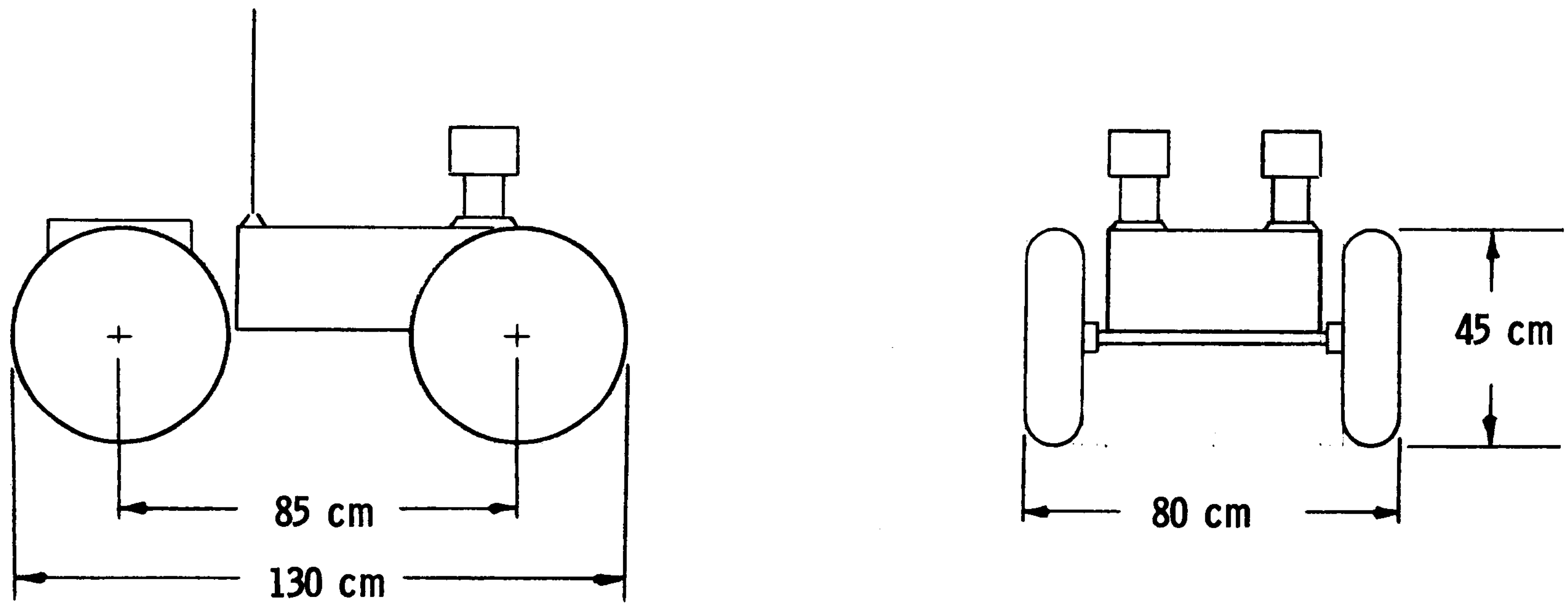


Figure II-19 Four-Wheeled Medium Rover



SAMPLE CAPACITY	2000 cc
DATA RATE	Receive 100 bps; Transmit 16 kbps
SCIENCE VOLUME	3.7×10^4 cc (1.33 ft^3)
POWER	25 Watt RTG

Figure II-20 Medium Rover Parameters

Table II-9 Mass Breakdown--Advanced Lander with Medium Rover

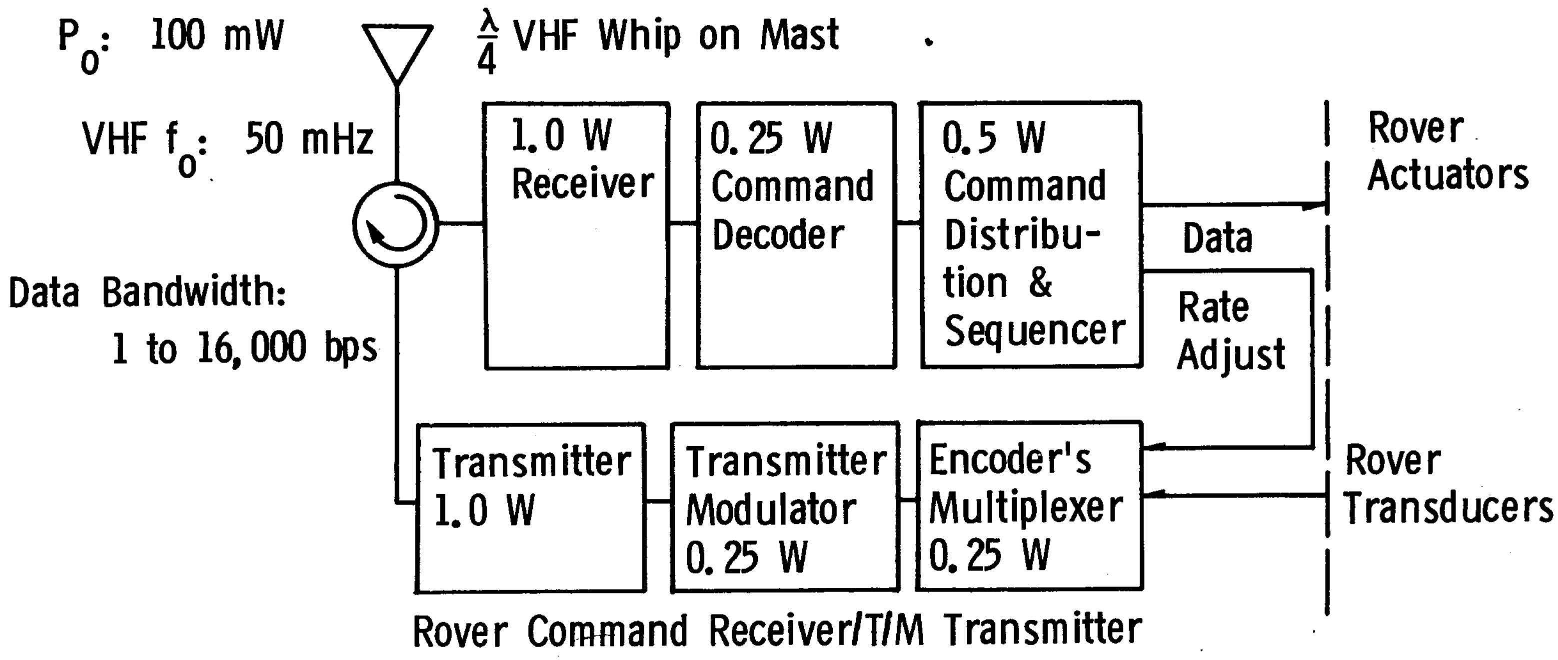
Subsystem	Current Viking '75	ΔWt	Advanced Lander with Medium Rover
Structures	106.6	+21.3	127.9
Propulsion	49.9	+29.0	78.9
Pyro	11.8		11.8
Thermal Control	28.1	+ 0.9	29.0
Power	98.4		98.4
Telemetry	19.5		19.5
G&C	62.7	+ 2.3	65.0
Comm	34.0		34.0
Harness	24.9	+ 4.5	29.4
Science	86.2	+120.3	206.5
Reserve	27.1		27.1
Res. Prop.	16.8		16.8
Press.	9.5		9.5
Landed Weight	575.5	+178.3	753.8 kg

communication link. Accordingly, a preliminary analysis of this link was made to determine if it would be a major constraint on system design and operation.

Initial requirements were established arbitrarily, namely, 16 kbps rover-to-lander data rate and line-of-sight ranges up to 10 km. The data rate corresponds to the high rate out of the Viking '75 facsimile cameras. A 50 MHz carrier frequency was selected to achieve reasonable whip antenna size (quarter wave = 1.5 m), low sensitivity to local terrain obstruction and multipath effects, and sufficient data bandwidth. The quarter wave antennas on the lander and rover must be deployed on masts at least 3 m tall to achieve 10 km line-of-sight range on a spherical Mars. In order for the systems to communicate reliably with either located in a major depression, taller antenna masts or shorter ranges are required.

Having established a set of general requirements and characteristics, conceptual designs were prepared for the rover and lander communication subsystems.

The functional identification and relationship of medium rover communications components is shown in Figure II-21. This implementation would employ the best available technology for the 1980s but should also be available with today's state of the art in solid state. The receiver responds to conventional FM/FSK command modulation and presents the NRZ data train to the command decoder and synchronizer. Commands can be stored in parallel in the command distribution and sequencer unit. A key feature proposed is a data rate adjustment based on received signal strength as sensed by the lander receiver and sent to the rover via the command link. This feature would represent an adaptive mode that could be used to maintain telemetry signal-to-



Volume:	
Electronics	2000 cm^3
Antenna & Mast	200 cm^3
Weight:	
Electronics	1.9 kg
Antenna & Mast	0.35 kg
Power:	
Operating	3.25 W
Standby	1.50 W

Figure II-21 Medium Rover Communications - Rover Components noise ratio and derive information on terrain physical properties in the communication path. The quarter wave whip would provide maximum antenna efficiency and bandwidth for the command and telemetry carriers. A standby mode would reduce power drain when the transmitter is inactive.

The lander components are shown in Figure II-22. The primary lander interface is with the GCSC computer and power subsystem. The quarter wave whip antenna should be placed so that there is minimal interference with the lander high gain and low gain antenna systems. This placement appears possible but requires further study. Components are all solid state and would make large use of microcircuit integrated electronic modules. The command rate maximum is set at 100 bits/second for this study. The radiative power is shown at 10 mw, but can be increased up to approximately 100 mw.

Analysis of these conceptual designs indicates that the communication system will not impose a major size, weight, or power constraint on the overall system.

A summary of the overall lander communications system capability is shown in Table II-10. This system assumes the use of the baseline Viking '75 lander and orbiter systems. The command uplink from Earth to lander and telemetry downlink from lander to Earth are at S-band. The data transmission time of 1.75 hours is based on two hours of S-band transmission from the lander with 0.25 hour devoted to acquisition of the downlink signal at the DSN ground station.

The command link should use error control to minimize delays caused by the need for confirmation and retransmission. Even using 100% redundancy (as with a 24, 12 BCH code), 585 words is more than sufficient for the presently planned medium rover

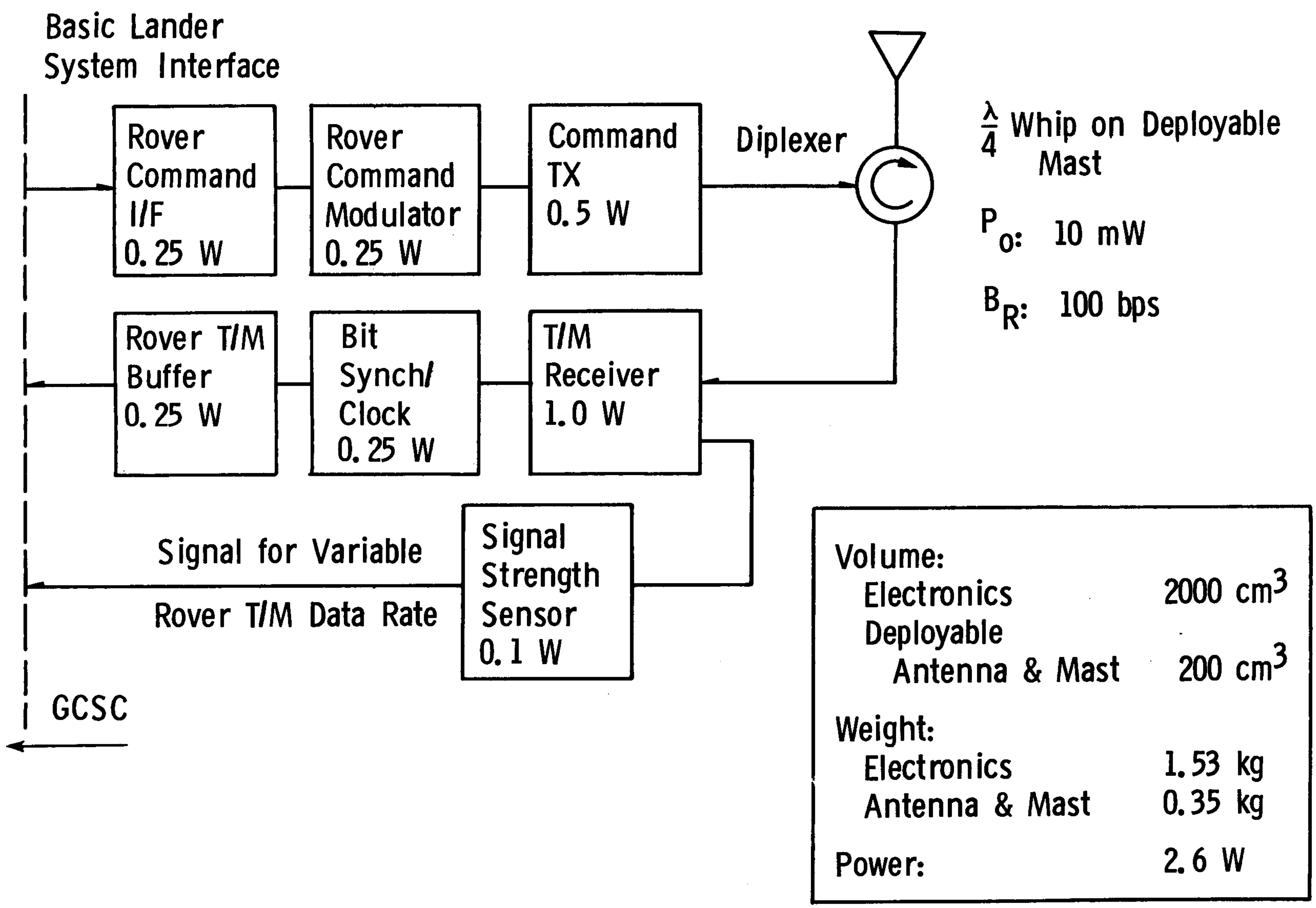


Figure II-22 Medium Rover Communications Subsystems - Lander Components

Table II-10 Overall Communications System Capability

MEDIUM ROVER TO LANDER-TO-EARTH AND LANDER TO ORBITER

COMMAND LINK - EARTH TO LANDER S-Band	4 bps
Data Volume - 1.75 hr contact time/24 hrs	25.2 k bits
Command Words (26 bit word)	970 words
With Error Control (24, 12 BCH)	585 words
COMMAND LINK - LANDER TO ROVER VHF (50 MHz)	100 bps
TELEMETRY - ROVER TO LANDER VHF	16 kbps
Lander to Earth - S-Band	250 bps
Data Volume/24 Hr (1.75 hr contact time)	1.6×10^6 bits
Lander to Orbiter UHF	16 kbps
Data Volume/24 Hrs	10^7 bits (min
Orbiter to Earth - S-Band	4 kbps

concept mission. The bulk of the telemetry data transfer to Earth will be via the UHF orbiter relay link. Future rover mission concepts may require a higher command data volume for computer updating.

Table II-11 shows the maximum Earth-Mars range and the system's communications capability for a ninety day mission after arrival for the launch years 1979-1988. The difference between these ranges and the maximum Viking '75 Earth-Mars range of 390×10^6 km is shown in dB. This can be used to increase the communication link capability (S-band or X-band) by the amounts shown.

Both the uplink command and downlink telemetry data rates can be increased by the use of X-band instead of S-band links. A theoretical gain of 11 db or a practical gain of 8 db can be realized (assuming transmitter powers, antenna apertures and receiver noise figures remain the same) by changing to X-band.

Some future advanced rover mission concepts may require a higher command data volume for computer updates. Calculations show that the command data volume obtainable with the X-band link and the same transmission time as S-band is in excess of 6000 words. This should be more than sufficient for these missions. The lander to Earth downlink telemetry data rate could be increased from 250 bps to 1.6 kbps and will accommodate a much larger science mission requirement.

Table II-12 shows a typical allocation of average power during landed operation. The energy requirements are controlled by modifying the operating time of the individual loads. The Viking power system consists of two RTGs rated at 35 watts each together with four 8-ampere hour nickel cadmium batteries which provide for peak power requirements above the RTG capability.

Table II-11 Communications Capability vs Launch Year

LANDER S-BAND DIRECT TO EARTH LINK OR ORBITER TO EARTH LINK

Launch Year	Mars Arrival Date	Max Earth-Mars Range (km) (90 Day Mission)	DB Difference From Viking '75	Permissible Data Rate Increase
1979	9-22-80	3.17×10^8	+1.8 dB	1.51 Times
1981	10-04-82	3.14×10^8	+1.9 dB	1.55
1983	10-10-84	2.63×10^8	+3.4 dB	2.19
1986	12-29-86	3.06×10^8	+2.1 dB	1.62
1988	2-14-89	3.28×10^8	+1.5 dB	1.41

Table II-12 Viking Lander Power Budget--Typical for 6th Day After Landing

Power Available	Watts
RTG Output	70.0
Converter Losses (86% Efficiency)	9.8
	60.2
Load Requirements	
GCSC	4.4
Communications	8.5
Telemetry	1.8
Power System	2.3
Battery Charging	10.4
Distribution Loss	1.3
Subtotal	28.7
System Margin	5.0
Subtotal	33.7
Balance Available for Science	26.5

The battery state-of-charge determines the degree of science loading that can be scheduled. Energy balance computations using a power system algorithm, would update the battery state-of-charge value. Inputs for these computations include RTG converter power output, battery voltage and temperature, and battery charge and discharge rates. Additional checks on battery condition may be provided by use of cell voltage and pressure sensors.

With regard to thermal control, the use of adaptive techniques is a natural approach to thermal design of landers for probablistic planetary environments. Unlike the classical approach of bracketing all possible environmental conditions by over-design, the adaptive technique selects a probable range of environmental conditions as a basis for the design, but provides survival capabilities during environmental extremes outside this range by the use of adaptive modes of operation.

For example, the lower (cold) accessibility limit of the Viking '75 lander may be considerably lowered at lower wind velocities, and would completely disappear during absence of winds. Hence it may be possible to extend the capabilities of the '75 lander to sub-polar landing sites by the use of adaptive control that limits the operations to calm days and provides survival capabilities for the windy days. Similarly, the hottest landing site on Mars is approximately 25 degrees C warmer than the hot extreme corresponding to the upper accessibility limit of the '75 lander. Operations on such a landing site are feasible, however, if only a part of the internal equipment is turned on at any given time, or if the operating modes are limited to the relatively colder days of the mission.

References

1. R. B. Seger: *VER-85, Surface Sampler, Effects of Increasing the Extended Length of the Furlable Boom to a Maximum of 20 Feet.* Martin Marietta Corporation, 9 October 1970. (Response to Viking PED Number VLC-101).

2. *STEM Design and Performance.* SPAR Aerospace Products Ltd., Toronto, Canada.

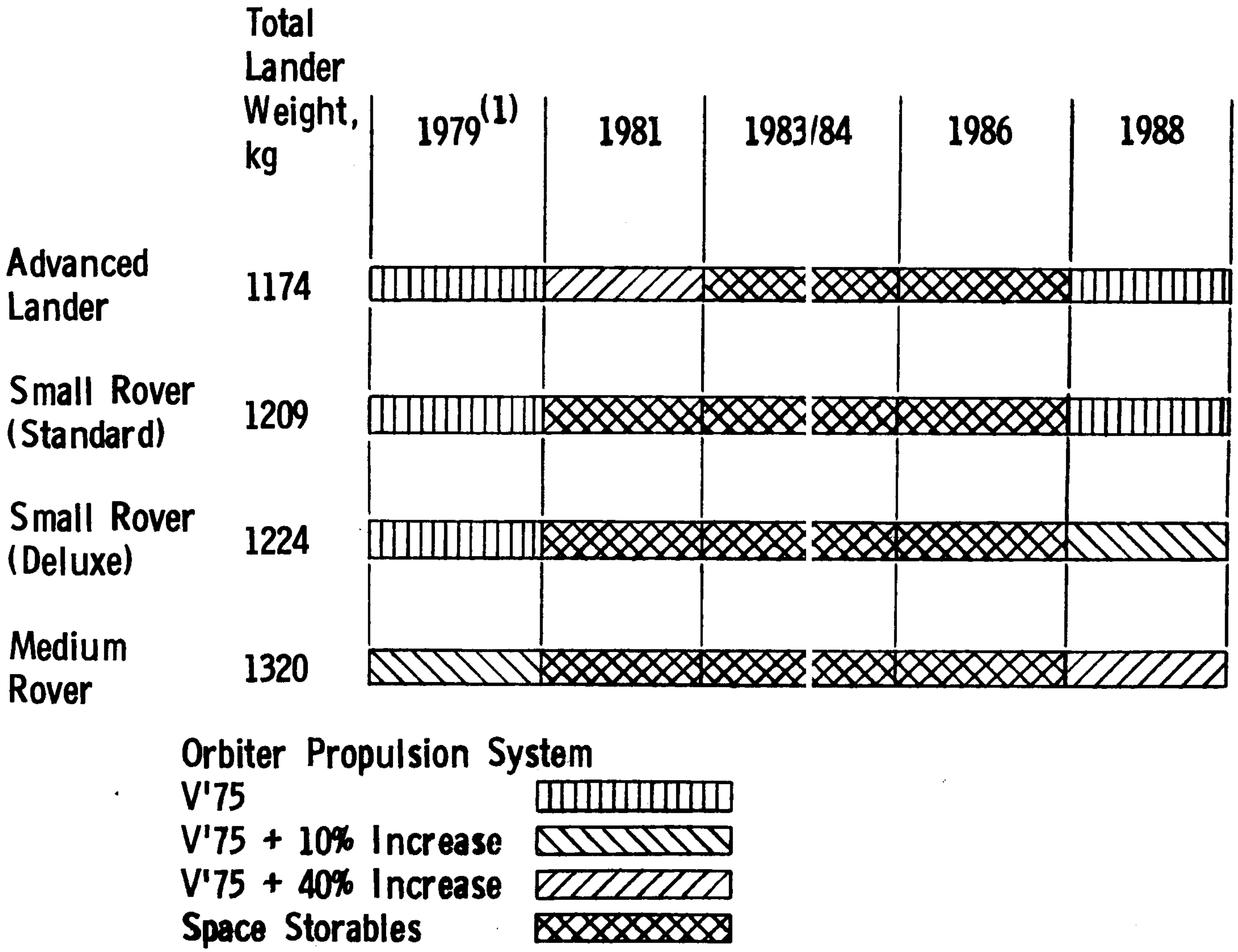
3. D. S. Crouch, W. R. Britton, and D. A. Lewis: *Backup Surface Sampler System Study.* TN-3770098, Martin Marietta Corporation (under Contract No. NAS1-9000), April 1971.

4. C. E. Farrell, W. H. Tobey, and J. H. Vowells: *Extended Surface Sampler (Rover) System Study.* TN-3770111, Martin Marietta Corporation (under Contract No. NAS1-9000, June 1971.

III. MISSION ANALYSIS AND DESIGN

The mission analysis and design portion of this study concerned itself primarily with the effects of the different lander concepts on the overall mission strategy and performance capabilities and requirements. The mission strategy is kept as similar to the Viking '75 as possible. The missions involve launches between 1979 and 1988 with launch opportunities occurring approximately every two years. The entire spacecraft is inserted into a synchronous orbit (24.6 hr) about Mars and the lander is deorbited after adequate landing site inspection is made by the orbiter. Existing subsystems are unmodified where possible and changed as little as possible where modifications are required. The effects of the different lander concepts were investigated and the required modifications to the lander were made as described in Chapter II. These changes were propagated backwards to determine the effects caused by the increased landed weight on the entry, deorbit, orbit insertion, and launch phases of the mission.

The launch system is the Shuttle/Centaur except for the 1979 opportunity which uses the Titan IIIE/Centaur. In all cases the launch system has adequate capability to inject the spacecraft. The orbit insertion requirements are quite variable over the different opportunities with a minimum impulsive requirement of 1050 meters/second in 1979 and a maximum of 1600 meters/second in 1983. This wide fluctuation requires different orbiter propulsion systems as indicated in Figure III-1. The Viking '75 propulsion system can be used in 1979 for all concepts except the medium rover which requires additional propellant. It can also be used for the advanced lander and



(1) The 1979 Missions Are Launched with the Titan IIIE/Centaur

Figure III-1 Mars Orbiter Propulsion System Requirements standard small rover concepts in 1988. The increased orbit insertion delta velocity requirements in the 1983/84 and 1986 (and most of the 1981 mission) opportunities result in the recommendation that space storable propellants be used (385 second specific impulse) since the use of the normal Viking propellants would require propellant load increases in excess of 40%. This value of 40% increase is considered to be a reasonable upper limit for increasing the propellant capacity of the current Viking '75 configuration.

The deorbit maneuver delta velocity requirements do not change with launch opportunity since the spacecraft is always placed in a synchronous orbit and the relative geometry between landing site and the orbit is constant. However, the increased weight of the lander does lead to increased propellant requirements for this maneuver. The current deorbit propellant load is adequate for all concepts except the medium rover, which would normally require the use of larger deorbit propellant tanks. However, a decrease in the delta velocity requirement is available by inserting the spacecraft into a synchronous orbit with a lower periapsis altitude (1000 km vs 1500). This strategy allows the deorbit maneuver to be performed with the existing propellant capacity and does not increase the orbit insertion requirement (actually a small delta velocity savings result).

The entry and descent sequence is indicated in Figure III-2. The times indicated are typical for a small deluxe rover and would change with entry weight, entry flight path angle and atmosphere. Table III-1 indicates the weight history during entry and descent for the different lander concepts. Several changes to the Viking '75 strategy are used to reduce the modification required by the increased lander weights. The flight

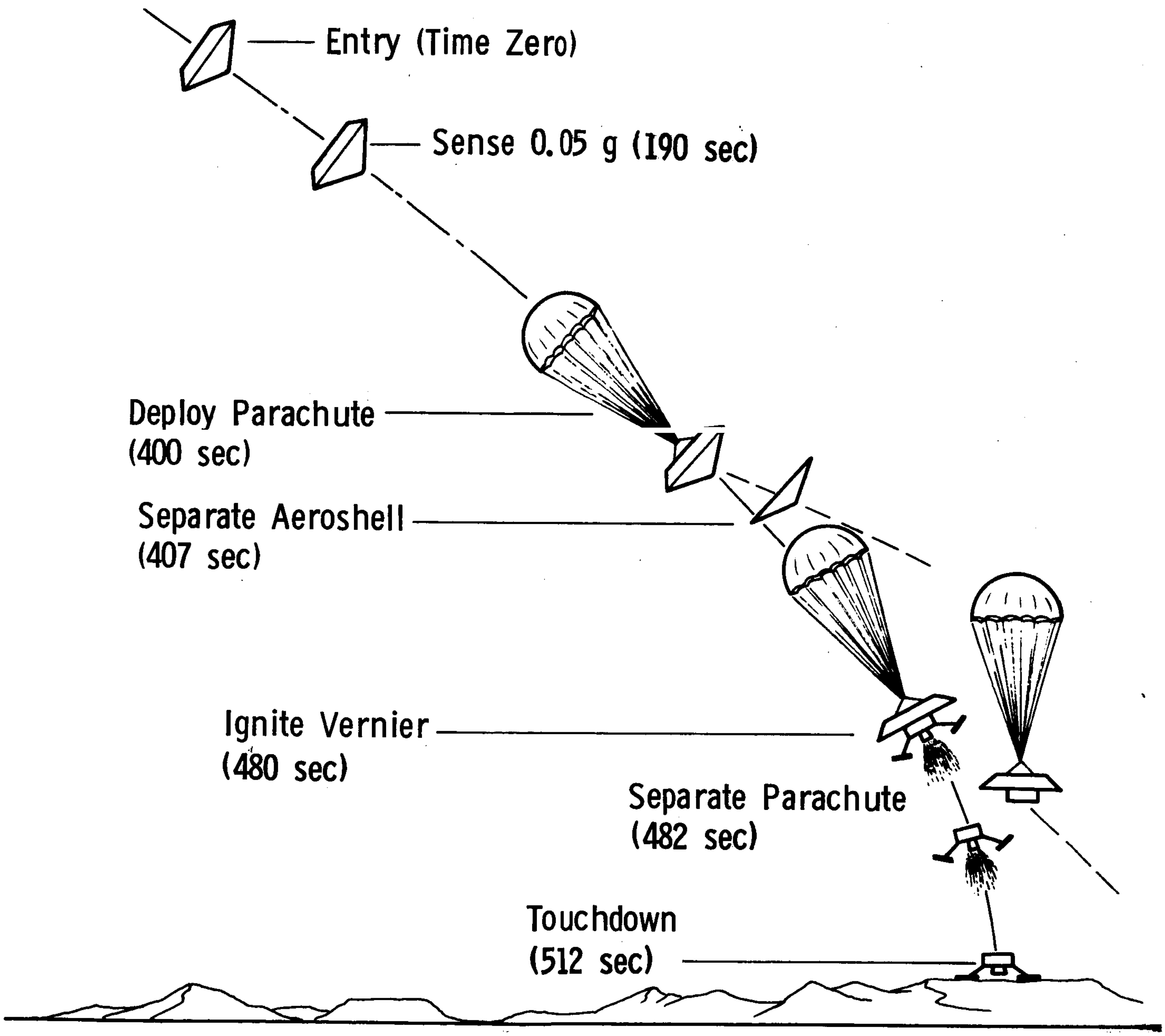


Figure III-2 Entry Touchdown Sequence of Events

Table III-1 Entry to Touchdown Weight Sequence

Event	Lander Weight (kg)				
	Advanced Lander	Small Rover Standard	Small Rover Deluxe	Medium Rover	Viking '75 Lander
Entry	992	1025	1041	1137	934
Separate Aeroshell	808	842	858	952	751
Separate Parachute	692	726	742	826	635
Touchdown	618	642	653	754	575
Total Lander Weight (at Launch)	1174	1209	1224	1320	1117

path angle corridor is reduced from 4^{o} (-15^{o} to -19^{o}) to 3^{o} (-15^{o} to -18^{o}). This reduces the maximum dynamic pressure for all concepts to less than the design limit of 7800 newtons/square meter. The flight path angle uncertainty does not cause this corridor to be violated, and the only result of the reduced corridor is a small decrease in lander down-range targeting capability.

The use of the revised mean Mars atmosphere and a terrain height capability of 1.5 km also decrease the impact of the increased lander weight on the various descent systems. Any significant increase in weight over the medium rover concept would violate the entry and parachute design criteria and probably result in a redesigned parachute and aeroshell. Table III-2 indicates the changes required on the various systems. The only changes to the advanced lander is the increase in terminal descent propellants by 14 kg (within current tank capacity). The two small rover concepts require additional terminal descent propellants of 24 and 29 kg (also within the tank capacity) and a small increment to the lander structure weight. The medium rover concept requires a slight increase in ablator thickness and localized changes in material to handle localized sheer stress problems and the increased heat load (maximum dynamic pressure and peak heat are kept within the design limits by reducing the flight path angle corridor). The terminal descent is modified for the medium rover concept to accommodate a six engine terminal descent system. This change increases the thrust-to-mass ratio to acceptable values. The thrust-to-mass ratio for the three engine concept is below the value required to prevent a hard landing. The lander structure is strengthened to accept the increased landing loads. Further details concerning these modifications are presented in Chapter II.

Table III-2 Descent and Landing Effects on Lander

	Terminal Descent	Parachute	Aeroshell	RCS Deorbit	Lander Structure
Advanced Lander	+14 kg Propellant (Same Tanks)	No Change	No Change	No Change	No Change
Small Rover (Standard)	+24 kg Propellant (Same Tanks)	No Change	No Change	No Change	.5 kg Structure Beef-up
Small Rover (Deluxe)	+29 kg Propellant (Same Tanks)	No Change	No Change	No Change	1 kg Structure Beef-up
Medium Rover	+13 kg Propellant (6 Engine T.D. System)	No Change	Local use of 3560 abl. matl. General abl. thickness increase.	No Change	5 kg Structure Beef-up

The landing latitude accessibility for a given mission is a function of the Mars approach velocity (VHE), the VHE vector declination with respect to the Mars equator, and the approach geometry (θ_{aim}). The maximum northern and southern latitudes which are obtainable using polar inclination ($\theta_{aim} = \pm 90^\circ$) are shown in Table III-3. These are the maximum landing latitudes consistently available throughout the thirty-day mission launch opportunity without apsidal rotation. Additional latitude is available by rotating the line of apsides during the orbit insertion maneuver. This requires additional delta velocity expenditures (and propellant) on the order of 25 m/s for 10° apsidal rotation, 80 m/s for 20°, and 150 m/s for 30°.

Table III-3 Landing Latitude Accessibility*

	1979	1981	1983	1986	1988
Maximum North Latitude	44°	35°	41°	72°	61°
Maximum South Latitude	80°	72°	71°	64°	62°

* No apsidal rotation utilized.

The thermal limits for the Viking lander are shown in Figure III-3. By finding the encounter date for a given opportunity and then finding the latitude lines which are always within the hot and cold limits for the desired mission duration, the latitudes available without thermal modification can be determined. For example the 1981 mission opportunity arrives in early September through mid-October of 1982 and for a 90 day mission would be within the current thermal limits in the northern hemisphere between 10° and 38° in latitude and there is no thermally acceptable region in the southern hemisphere. To make this figure

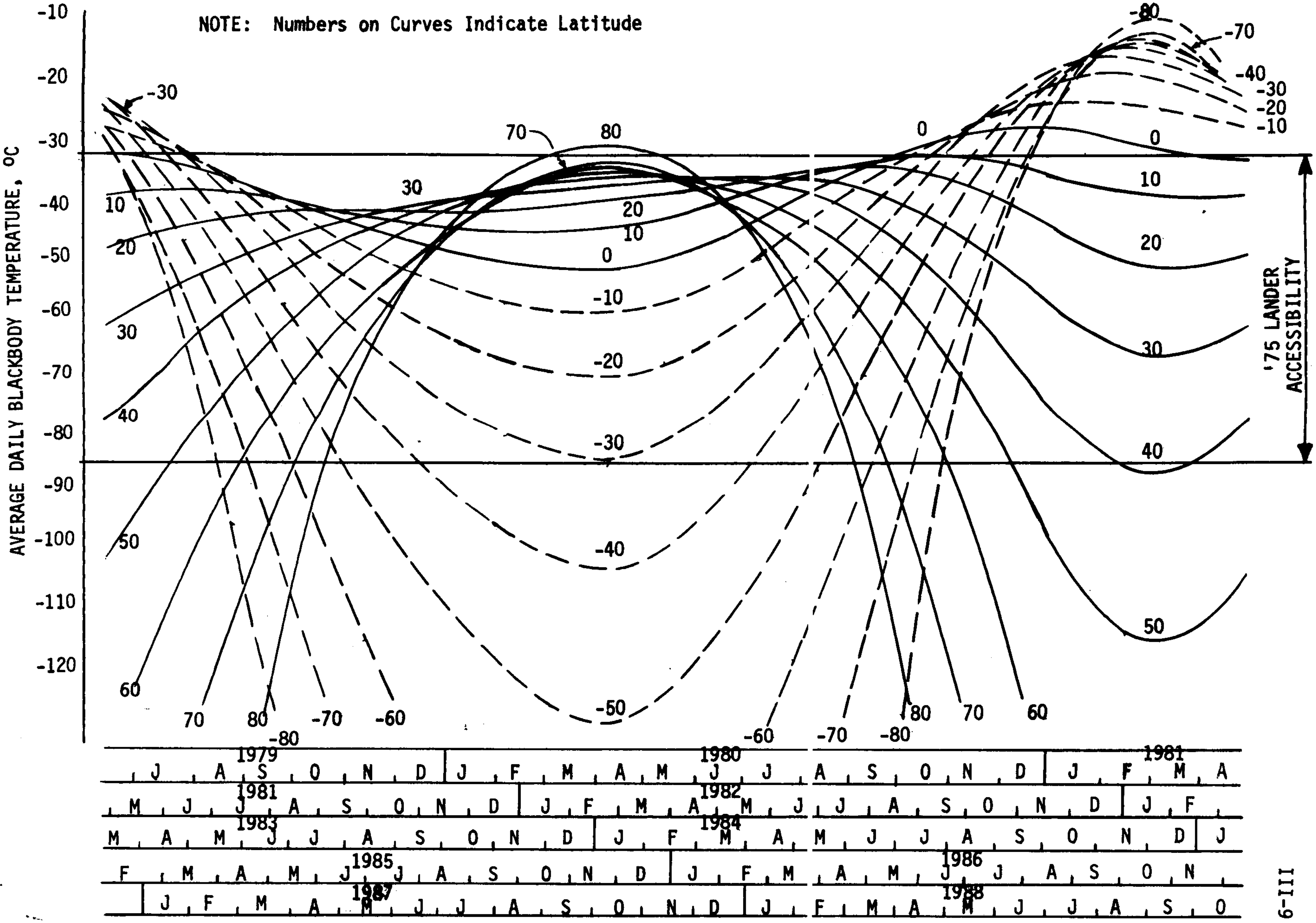


Figure III-3 Thermal Map of Mars & Viking '75 Lander Accessibility Limits more useable, Table III-4 contains the span of arrival dates for each launch opportunity considered in this study.

Table III-4 Arrival Dates for Each Launch Opportunity

Launch Opportunity	1979	1981	1983/84	1986	1988
Earliest Arrival	08-27-80	-9-04-82	09-12-84	10-20-86	01-09-89
Latest Arrival	09-22-80	10-04-82	10-10-84	12-29-86	02-14-89

It is also anticipated that approximately 10 days will be spent in orbit after the actual arrival date before landing takes place and this period of time would need to be included in determining the actual landed period and the thermal environment during this time. Thermal modifications are potentially available to allow missions in the excessively hot areas (phase change material) and also for the excessively cold areas (heat pipe arrangements utilizing heat from the RTGs).

IV. ADAPTIVE SCIENCE

This chapter describes the science system and how its performance can be increased or its cost decreased with on-board decision making.

When adaptive systems are discussed, a typical reaction of scientists and others with mission experience is to be skeptical of the ability of a simple computer to make good scientific decisions and a concern that by attempting to make a smart system we may get one that systematically makes very bad decisions and ends up with less good data than would have been obtained with preprogrammed set of actions. These fears are well-founded, and have been constantly in mind during the study of adaptability. The goal has not been to put scientific judgement into a computer, but rather to give the scientists a tool that enables them to automate some simple decisions so that they can be made on the lander or rover and carried out promptly enough to do some good. A first principle, then, is to put the adaptive system as directly as possible under the control of the scientific teams.

A second principle that should be followed on any mission of long enough duration is to start with a minimum of autonomy and increase it as confidence is gained. For a Mars lander with rover, typical action the first day or two after landing will include exercising systems to verify their condition. The diurnal temperature and light cycles will be established. The rover will be deployed and traction will be measured on the Martian soil. At this stage few decisions are made on Mars.

As confidence increases, more decisions will be made by the on-board controller. The fixed schedule of actions and measurements will be replaced by a flexible one based on priorities. The priorities will be determined in part by the observations so that recording of transients and unusual phenomena will replace less valuable activities.

Toward the end of the mission, the region close to the lander will have been thoroughly explored, and the rover may be sent on long excursions, even out of communication range, since the chance of finding something new will be worth the risk of losing the rover.

As Section B "Adaptive Reactions" is read, it should be kept in mind that it is not proposed to turn the lander and rover loose with a large bag of untried tricks but rather to ease into adaptability and to tailor the criteria, thresholds, and logic according to experience and the actual conditions on the surface of the planet. If the system is designed with flexibility, great advances in adaptability can be made in a single mission, but if it is attempted to foresee exactly how the system should react a long series of missions will be required for the same progress.

A. SCIENCE SYSTEM

Tables IV-1 and IV-2 list the instruments for the lander and the rovers with their expected scientific values. The numbers in the "Adaptive Modes" column are keyed to the enumeration in Section B below.

The locations of the instruments are indicated in the drawings of the three landed systems in Chapter II.

Items 15 and 16 in Table IV-1, the Soil Sorter and Instrumented Boom are believed to be new ideas and will be described below.

Soil Sorter - This feature is not included in our baseline lander because it needs considerable design study before it can be sized. If it is feasible it could significantly increase the scientific output of a lander.

A sample of sand or dust taken anywhere on a windy planet is likely to consist of grains of many different types. Some of the grains will be made up of 2 or more crystals of different mineral types, but many of the smaller ones will be single crystals. The grains will be derived from sites representing most if not all of the geologic domains of the planet.

Viking will treat the soil samples as though they are homogeneous and will determine the elemental composition and other priorities of the mixture. Much additional scientific value would be obtained if the soil could first be sorted into its component types which would then give information about their respective sites of origin.

To classify the soil particles it is first necessary to separate them. This is the kind of materials handling problem

Table IV-1 Scientific Value and Adaptive Modes of Instruments - Lander

	Instrument	Scientific Value	Adaptive Modes (Single Input Class)
1.	Fax Cameras	Geologic setting of landing site: morphology of land forms; rock and particle size distributions; constrain mineralogic composition from spectral reflectance. Meteorologic observables: morphology and spectral properties of clouds, aerosols, and dust. Wind dynamics from cloud, dust dynamics. Biological observables: motion; exotic features.	1, 2
2.	Sample Magnifier	Erosion mechanisms via particle morphologies, size distributions. Constraints on soil composition.	- - - - -
3.	Planetary Landing Site Selection System (PLSSS)	Achieves landing at pre-determined geologic setting. Vidicon supplementary to lander camera.	3, 4, 5
4.	Adv. Surface Sampler	Soil physical properties.	6, 7
5.	Drill	Soil physical properties with depth.	8
*6.	Soil Gas Sampler	Soil-atmospheric gases equilibrium profiles (with depth) and reaction rates. Possible indication of life via disequilibrium.	9, 10, 11, 12
7.	Integrated Geology (XRFS, ABS, XRD, DSC/EGA)	Bulk planetary differentiation from chemistry (major, minor, and certain trace elements). Geologic history from chemistry and mineralogy (prior history of liquid water?). Content and types of water and other volatiles in soil (adsorbed, trapped, hydrates, etc.).	16, 17, 18, 19, 20

(continued)

* Indicates instrument not in baseline.

Table IV-1 Scientific Value and Adaptive Modes of Instruments - Lander (continued)

	Instrument	Scientific Value	Adaptive Modes (Single Input Class)
8.	Wet Chemistry Analyzer	Amino acid levels and fingerprint (abiotic-like?, earth-like?, exotic?). Optical activity as indicator for life and/or time since extinction.	21, 22, 23
9.	Adv. Biology (Stable Isotope)	Life detection via metabolism. Biochemical characterizations: substrates; kinetics; products. Micro-environment: salts, pH	24, 25, 26, 27, 28, 29, 30
10.	Meteorology (temperature, pressure, wind, humidity)	Structure of the base of the boundary layer. Diurnal and seasonal dynamics. Detect medium and small-scale systems (fronts, dust devils, etc.). Water vapor cycle.	31, 32
*11.	Rocket or Balloon	Wind patterns above the boundary layer. Structure (temperature, pressure) of the atmosphere especially as a function of time in the diurnal cycle.	33

* Indicates instrument not in baseline.

(continued)

Table IV-1 Scientific Value and Adaptive Modes of Instruments - Lander (concluded)

	Instrument	Scientific Value	Adaptive Modes (Single Input Class)
12.	Seismometer	Level and source regions for microseismic and tectonic activity. Bulk planet structure (core?). Constraints on bulk planet composition. Meteorite influx rate.	34, 35, 36, 37, 38
*13.	Age Dating	Crystallization date of surface material.	- - - -
*14.	Ion Mass Spectrometer	Ionospheric composition (bears strongly on escape rates).	- - - -
*15.	Soil Sorter	Detailed analysis of soil by types of grains.	- - - -
*16.	Instrumented Boom	Permits analysis of bed-rock from lander. Close-up inspection of soil layers and undisturbed structure.	- - - -

* Indicates instrument not in baseline.

Table IV-2 Scientific Value and Adaptive Modes of Instruments - Rovers

	Instrument	Scientific Value	Adaptive Modes (Single Input Class)
1.	Photometric Target	Atmospheric aerosol content. Absolute albedo of surface material.	- - - -
2.	TV and Mirror	Landing site alteration effects (see lander camera for other scientific values)	41, 42
3.	Scoop and Trays	Soil physical properties.	39, 43
4.	Sifter	Particle size distribution.	- - - -
5.	Drill	Soil physical properties with depth.	49
6.	Rock Grabber	Soil physical properties.	- - - -
7.	Neutron Activation and Scatter	Soil chemical composition, including trace elements. Hydrogen content (water, organics).	47, 48
8.	XRFS	Chemical composition profiles (surface heterogeneity).	40, 50
9.	Clinometer/Odometer/Gyro	Topography; soil mechanical properties.	- - - -
10.	Organic Sieve	Quantity and distribution of organic matter in surface material.	52
11.	Meteorology	Structure and dynamics of small scale systems.	51
12.	Seismometer	Same as Adv. Lander Seismometer, except deployment should enhance effective sensitivity.	46
13.	Seismic Source	Structure of the local overburden (permafrost, depth of the regolith).	- - - -
14.	Gamma Spectrometer	Concentrations of the naturally radioactive elements (K, U, Th) as indicator of planetary differentiation.	44, 45

that is routinely faced for instance in the food packing industry where items of irregular size and shape are graded and placed into containers. On Mars, one can envision a preliminary size grading with seives followed by a slow discharge from a hopper onto a moving belt or disc so that the grains are widely scattered and touch one another only rarely.

If sufficient counting rate can be achieved, an ideal sensor for classifying mineral particles is the x-ray fluorescence spectrometer. The x-ray source should be collimated to give a beam about the diameter of the smallest grains, perhaps a tenth to half a millimeter. The conveyor belt or disc can be made of a material such as polyethylene that will not interfere with the fluorescent spectrum. The surface of the belt can be searched for grains by a combination of longitudinal belt motion combined with a transverse scan of the x-ray source and detector. The search mode terminates when a grain is detected, at which time the belt and source motions are servoed to the position of maximum count.

Classification according to elemental composition is a simple computer task. When a grain has been classified, its position on the belt is memorized, and it is dropped into the appropriate bin by a combination of motions of the belt, bins, and possibly a small brush to nudge it off the belt.

Unusual grains, i.e., ones of composition unlike those that have previously been examined, could be moved within range of an automatically focusing microscope so that their pictures in wide band color can be recorded before they are put into bins.

It may turn out that individual grains are too small to give good x-ray fluorescent counting rate. In this case the microscope should be used for classification according to color, and the XRFS should be used for elemental analysis when enough similar particles have been accumulated.

When a bin contains enough material for the scheduled tests, further grains of that type are discarded.

The monocrystalline grains should fall neatly into classes. Composite grains will be recognizable by having intermediate compositions. Study of the distributions will yield information on which minerals occur together, and it may even be possible to determine the composition of the original rocks from which the grains were broken.

Instrumented Boom - This is another speculative feature not included in the baseline system.

If the lander sits down on a rocky surface from which the soil has been blown away, it may be impossible to get a sample into the lander for analysis. In this case the analytical instruments must be taken to the samples. A radio-active x-ray source and a proportional counter can easily be mounted on the sampler boom. The source and counter can now act as a proximity detector to help guide the boom over the surface of the rock, and the x-ray fluorescence spectrometer (XRFS) will give the elemental composition. A microscope, even a crude one, mounted on the boom will give valuable scientific information as well as pictures that will be interesting to the general public.

A boom-mounted microscope will also be useful in sand or dust to get pictures of the undisturbed soil. If the boom digs a trench, the microscope can observe the layers revealed in the trench wall and yield information on the dust-storm history.

An adaptive feature desirable for the instrumented boom is automatic means to guide the boom over the surface while it gathers data. Using the microscope or the XRFS to discriminate mineral types, the adaptive system can search for rare components or get data on crystal size and abundances. Automatic focusing of the microscope is also needed.

B. ADAPTIVE REACTIONS

This section enumerates the adaptive reactions that appear valuable for the Mars lander and the lander-rover combinations. They have been divided into 2 classes according to whether they involve the operation of a single instrument or require interactions between instruments. This distinction takes on significance in Chapter V when the computer organization is described. The single input reactions will be controlled by operating routines, while the multiple input reactions require the executive controller in addition.

Some items are self-explanatory. Others are described in more or less detail. Where possible, an assessment of benefits has been made.

The single instrument reactions follow.

1. Lander Camera

Select filter and electronic gain and offset for maximum picture contrast.

Benefits Could save the first day's pictures and any pictures taken after sudden changes in atmospheric dust content. Will also save time of scientists and decrease load on the command system.

2. Lander Camera

Apply data compression algorithms. Select most appropriate algorithm for each picture. Assign recovery priority to each picture.

3. PLSSS System

Adaptively adjust terminal propulsion to land in safest landing area.

The landing site selection system is an aid in putting the lander down in a smooth area to reduce the chances of tumbling or damage by large rocks that could touch the body of the lander. The landing site selection system would start operating after the lander's aeroshell is jettisoned. A TV camera images the scene below including the landing footprint, i.e., the area that can be reached by maneuvering the lander. This area is divided into 16 regions that are evaluated for roughness with a simple filtering and threshold circuit. The lander is then guided toward the region of minimum roughness.

Benefits Increased chance of success. Increased choice of landing region with acceptable safety.

4. PLSSS Vidicon

Adjust field-of-view and timing during descent to obtain nested photos. Optimize photo-taking during terminal phase to provide data to plan rover sorties.

Adaptive features include exposure control and sensing the attitude variations of the lander to avoid making pictures at the peaks of the attitude swings.

Benefits Provides exact location of landing site on orbiter pictures. Increases rover safety and efficiency.

5. PLSSS System

During entry, use a correlation mode to steer the entry vehicle toward a predetermined surface feature (footprint reduction). Prior to parachute deployment, switch to contrast avoidance mode for safe landing.

Benefits This terminal guidance system permits landing precisely at a feature identified from orbital observation. It is much cheaper than inertial guidance of comparable accuracy.

6. Boom Sampler

When processor soil level sensor indicates inadequate sample obtained, repeat acquisition sequence (max of N times).

7. Boom Sampler

Repeatedly lower boom to surface until contact, with sequential boom extension to measure surface profile. Computer then directs boom movements that allow (1) sampling from topmost surface layer, or (2) traversing a short distance above surface to allow magnetic pickup.

8. Lander Drill

Adjust feed rate for maximum penetration at minimum energy expenditure and to measure mechanical properties of material.

9. Lander Drill

Adjust auger insertion rate to avoid soil compression and to stay within the performance ratings of the mechanisms.

10. Soil Gas Sampler

Throttle gas purge to adaptively match soil permeability and inject gas most efficiently.

11. Soil Gas Sampler

Sample collection intervals determined by reaching critical pressure values in effluent stream.

12. Soil Gas Sampler

Adjust heater power to maintain constant temperature rate in soil.

13. Lander XRFS (X-Ray Fluorescence Spectrometer)

Terminate data accumulation as soon as data satisfies minimum statistical criterion.

The strategy and benefits are the same as discussed under 24 below.

14. Lander XRFS

Compare spectra with previously taken results to determine whether sample is unique. If it is, increase counting time.

15. Lander XRFS

Employ calibration flag if K ratio is very large or very small. Program calibration flag frequency based upon temperature rate of change.

Because the potassium and calcium lines overlap, it is hard to measure a small amount of one in the presence of a large amount of the other. Adaptive reaction is to calibrate with a pure Ca or K target and increase the counting time. Temperature changes will upset the spectrometer calibration. The adaptive system will automatically recalibrate when the temperature changes more than a specified amount.

Benefits Good spectra will be obtained every time. It will not be necessary to hold a sample until the spectrum has been examined on Earth to see whether it needs to be repeated. Many more samples can be processed.

16. Alpha Backscatter

Dump data each time the temperature change exceeds a preset limit.

Temperature drift during the long counting time changes the energy calibration and smears the spectrum. Dumping (recording) the data more often when temperature change is rapid permits reconstruction of a good spectrum.

Benefits Permits cruder temperature control and saves cost.

17. Alpha Backscatter

Frequency of internal calibration is tied to temperature changes.

Same as 15 above.

18. X-Ray Diffractometer

Goniometer dwell time is varied on statistical criterion to enhance accuracy while minimizing analysis time.

Same as 24 below.

19. X-Ray Diffractometer

Increase counting time at certain critical angles.

X-ray diffraction is extremely valuable because it permits identification of mineral types by their crystal lattice parameters. Counting time is usually long, and it can be reduced somewhat by the method already described--counting for a shorter time where the rate is high. However, the typical spectrum is mostly background and has only a small percentage in high peaks where time can be saved.

There is a more promising way to save time (or improve results with fixed time). It is important to get good signal-to-noise ratio on the shoulders of the peaks to fix their angles precisely and also to detect smaller peaks that tend to be masked by larger ones. After a fast scan, additional time can be given to critical angles.

Benefits Better spectra with less instrument time, and therefore more samples analyzed. An alternative is to save cost with a weaker x-ray source requiring less weight in shielding.

20. Water Detector (DSC/EGA)

Temperature error signal sent to adaptive controller, which adjusts and measures power required to null error.

21. Wet Chemistry Analyzer

Monitor progress of reactions and adaptively control operating parameters (temperatures, pressures, times, etc.) and sequencing.

This equipment analyzes soil samples for the presence of optically active amino acids. On Earth, these are produced only by living things.

The operation is complex. In one design of the experiment, 70 actions are performed in a sequence at 34 different times. Eight temperatures are controlled. Twenty-four valves are used to control the progress of the sample and the addition of nine reagents and other consumables. The experiment is adaptive in that it uses temperature sensors, a liquid level detector, and a detector for ammonium hydroxide. Unless it is put in a landed system that is designed to furnish computational services to the experimenters, the control system must be provided by special hardware at considerable cost in design, weight, and verification and a loss in flexibility. The current approach is to design the chemistry to minimize the need for adaptability. If adaptability is easily provided by the central computer, the requirements on the chemistry may be relaxed yielding a further decrease in cost.

Benefits Reduced cost in development and hardware. Successful operation over wider range of soil composition, etc.

22. Wet Chemistry Analyzer

Use peak-selector algorithm to compress data from gas chromatography detector.

23. Wet Chemistry Analyzer

Safe the instrument in case of a power dropout.

24. Advanced Biology

Analyze mass spectrometer quick scan for results and adjust dwell times of the following scan to maximize accuracy.

In mass spectrometers and many other instruments, events are counted to measure abundances or other parameters. The number of events actually counted in given time interval is a statistical quantity whose standard deviation (rms error) is equal to the square root of the expected number of events. If, for instance we want the standard deviation in the abundance of each mass number to be less than 3%, about 1000 counts are needed for each mass number. In ordinary practice, the counting time at each mass number is the same and is chosen to give an adequate number of events for the more rare mass numbers and many more events than are needed for the abundant mass numbers. Of course some compromise must be made with any specification of a percentage error for the very rare mass numbers.

Because the abundances typically range over many orders of magnitude, considerable time can be saved by using variable counting times. A simple rule is: count until N events are counted or T seconds have elapsed; record the time for N events or the number of events for T seconds. Using this rule on typical mass spectra (for example see R. Radmer and B. Kok in *Life Sciences and Space Research X*. Akademie-Verlag, Berlin, 1972) reduces counting time by a factor of 2 or better.

Benefits Counting time is reduced. For the advanced biology experiment this means less gas is needed, and the saving can be realized in greater experiment life or greater sensitivity. Either way the chance of detecting life is increased.

25. Advanced Biology

When a change in gas composition occurs for a given cell, increase sampling rate to better define the kinetics of the reactions.

The distinction between ordinary chemical reactions and those mediated by living organisms will be based on the rates and shapes of their variations with time. Some reactions will be slow. Others will go rapidly at first and then stop. Organisms that are dormant may show no activity for many days and then metabolize rapidly after awakening. Figure IV-1 shows some of the types of curves that have been obtained with terrestrial soil. Choosing the frequency for sampling the gas is difficult. If it is too long the sudden changes will not be recorded in detail, and if the gas is sampled too often it may all be used up before the action starts.

Some relief will be obtained by taking the next sample after a time that depends on the rate of change indicated by the results of the last two samples. This is illustrated by the crosses in the figure. Changes can be monitored for all the mass numbers so that a rapid increase or decrease in any component will decrease the sampling rate.

Benefits Quantitative evaluation of the benefits of adaptive sampling rates depends on the expected reaction dynamics, but a 50% saving of gas with an improvement in the scientific value seems conservative. If adaptive counting is also used, a given amount of gas can probably be made to last from four to 10 times as long.

26. Advanced Biology

Safe the instrument when power is transiently removed (power dropout).

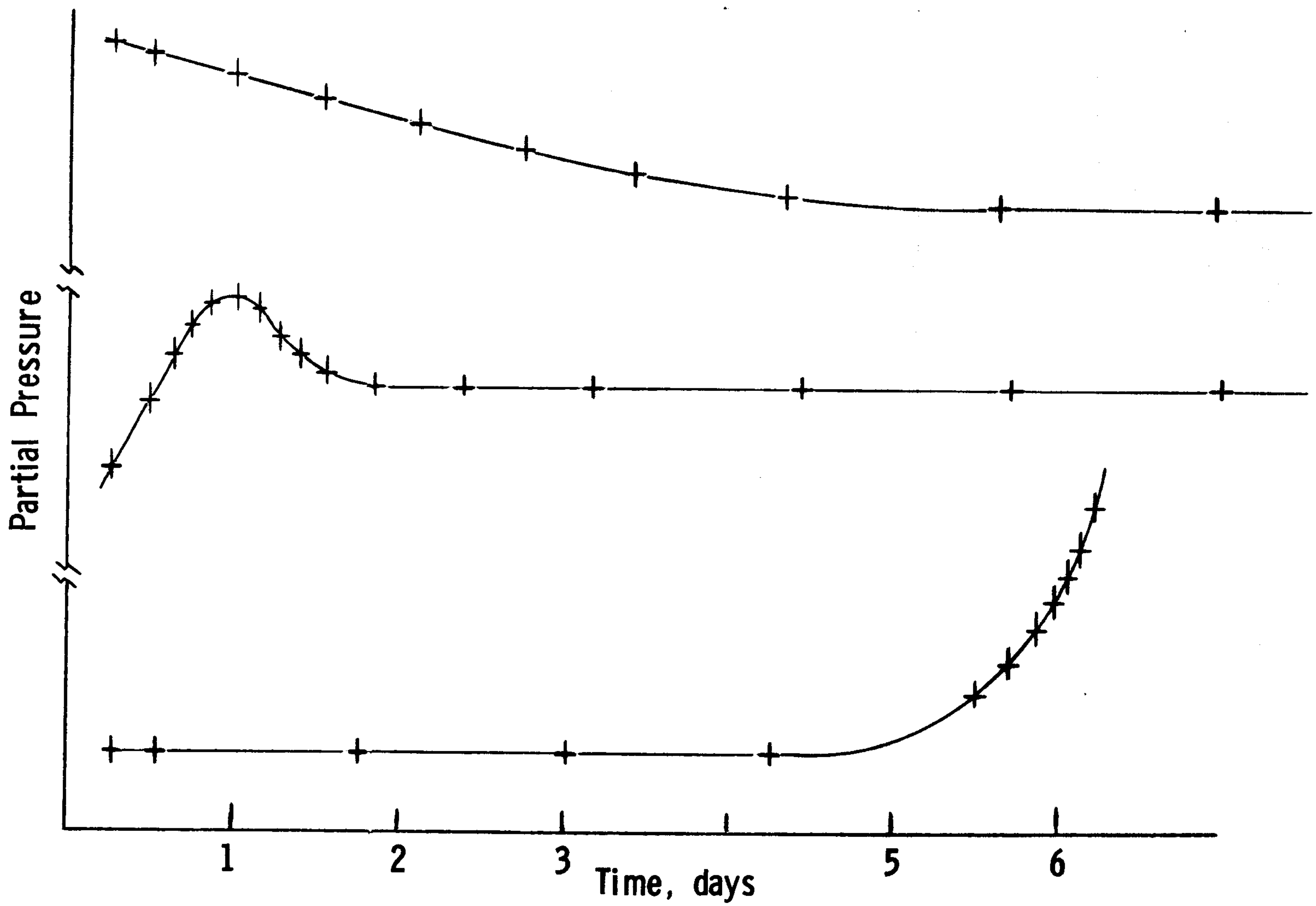


Figure IV-1 Advanced Biology - Adaptive Sampling Rate

27. Advanced Biology

Servo control the opening of the leak valve to reach minimum acceptable signal.

28. Advanced Biology

Adaptively determine nutrient additions (e.g., add at plateau point to determine whether substrate limited or organism limited metabolism).

29. Advanced Biology

If leak valve becomes stuck in the open position, cycle valve until shut-down occurs. If valve refuses to clear, actuate back-up valve.

A malfunction of a sampling valve could be catastrophic since it would soon bleed off the precious gas from the test cell. Corrective action from Earth would be much too late to do any good, but on-board detection of failure to shut off could trigger a cycling of the valve to attempt to get rid of a particle in the seat, and if that fails a back-up valve can be closed.

Benefits Reduced cost by substituting software for extremely expensive development and qualification of ultra-reliable valves.

30. Advanced Biology

For temperature effects experiments, control power input to achieve desired temperature rise and/or inactivation rate.

31. Lander Meteorology

Whenever temperature, pressure, or humidity are not nominal (i.e., disagree with data previously obtained for that time of day), go to high data rate mode.

32. Lander Meteorology

For wind speeds greater than a critical threshold go to high data-rate mode and test for variability. If gusts detected, switch to near-continuous readout of wind velocity vector.

33. Rocket/Balloon

Adaptively decrease rate of data accumulation and transmission as range increases, and/or as velocity decreases.

34. Lander Seismometer

Trigger seismic source when background is low.

Background noise will vary widely. On Earth the seismic amplitude at the quietest times may be 1/10 of the typical value. We can also expect large variations on Mars especially if wind is a major cause of the noise.

For active seismometry, the command to detonate a charge will not be executed until the noise is low. Since the amplitude of the artificial seism is nearly proportional to the mass of the explosive charge, the charge can be reduced in the same ratio as the background noise amplitude.

Benefits With the conservative assumption that the noise can be reduced to 1/5 by choosing quiet times, the benefits can be realized as an 80% saving in charge weight, 5 times as many shots, or a distance increase in the same ratio. An alternative is to reduce cost by leaving the seismometer in the lander (instead of deploying it) and relying on the adaptive system to choose a time when the lander is quiet.

35. Lander Seismometer

Apply data compression algorithms. Type of algorithm is selected according to amount and characteristics of data accumulated.

36. Lander Seismometer

Prioritize natural events in order of desirability of retrieval, with low priority for monitoring of lander mechanisms actuations.

37. Lander Seismometer

Adaptively adjust sensor tilt after landing until true level is attained.

38. Lander Seismometer

Select maximum bandpass required during recording of a natural event.

39. Small Rover (SR) Scoop

Adaptively repeat sample acquisition until adequate amount of material is collected.

40. SR XRFS

Store cumulative spectral data during traverse to establish baseline composition. Detect changes in composition by spectral differencing.

This type of transition detection is discussed in Volume II.

41. SR TV

Process images using rock finding algorithm. Take close-up photos of detected rocks.

The algorithm is detailed in Reference 1*.

Benefits See 42 below for an example of how this adaptive mode can be used.

42. SR

Use sensors and adaptive capabilities to manipulate the environment.

A major reason for having a rover is to manipulate the Martian surface and go part way toward bridging the gap between a passive observer and a geologist on the scene with hands, feet, and hammer.

An adaptive system that uses the outputs of force and position sensors on the sampling arms and rover drives will be able to do such things as digging trenches and testing the mechanics of the soil much more efficiently than a non-adaptive system that can only be commanded in terms of wheel revolutions and specified displacements and angles for the sampling arms.

As a typical interactive task, consider how a rover would turn over a rock on the surface so that its underside can be observed. The strategy for the small rover is to drive its sampler against the rock slightly below the surface and then lift the rock and roll it over by a coordinated raising of the sampler and forward motion on the rover's wheels (see Figure IV-2).

---

* References listed on page IV-34.

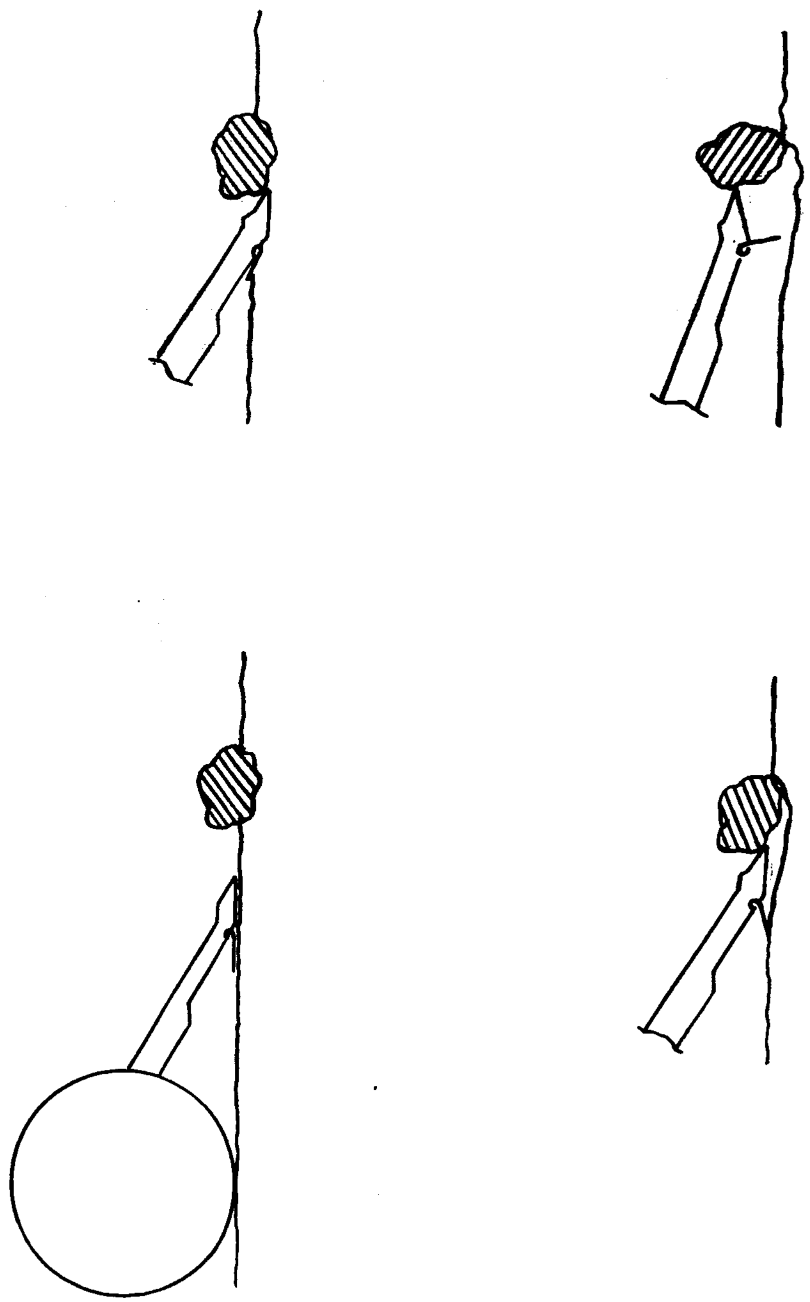


Figure IV-2 Turning Over a Rock

The unadaptive rover's first problem is making gentle contact with the rock. The rock should be lifted out and not pushed horizontally destroying the information in the soil beneath it. The approach must therefore be made in several approximations each of which require a one-day turn-around time if an orbiter relay is used.

When lifting starts it must be done cautiously. If the rock does not move, the rover can turn itself over with its sampler.

Coordination between forward motion and lifting will be difficult at best. The unpleasant alternatives are small incremental motions each requiring a day of elapsed time and bolder action with risk of dropping the rock.

The adaptive system has everything needed to get the job done in one day with one set of commands. Since several different actions will be commanded with one transmission, it is probably a good idea to check them out on Earth with a duplicate rover and a rock of about the same size and shape (the underground shape can only be guessed at) in similar soil.

The rock-finding algorithm described in Reference 1 can be used here for terminal guidance, although other methods are also possible.

Benefits Table IV-3 compares the time required for this task with non-adaptive and adaptive systems.

43. SR Scoop

For attempt to pick up a rock, cycle the acquisition sequence until a rock is detected in the hopper.

Table IV-3 Turning Over a Rock with a Rover

Non-Adaptively

Day 0	Scientist sees rock 5 m from rover. Requests that it be turned over and photographed.
Day 1	Rover approaches to 1 m from rock. Makes picture.
Day 2	Rover approaches to 0.1 m from rock. Makes picture.
Day 3	Rover pushes sampler against rock. Raises sampler 5 cm. Makes picture.
Day 4	Rover drives forward 1 cm, raises sampler 5 cm. Drives forward 2 cm, raises sampler 5 cm. Makes picture.
Day 5	Rover drives forward 20 cm. (Rock falls over.) Makes picture.
Day 6	Rover drives backward 1 meter and makes picture.

Adaptively

Day 0	Scientist sees rock 5 m from rover. Explains to rover specialist that he wants it turned over and photographed. Rover specialist writes set of instructions.
Day 1	Instructions are now tested using duplicate rover in laboratory on Earth. Revisions are made until operation is satisfactory.
Day 2	Rover approaches within 1 m of rock. Locates it exactly with camera and rock-finding algorithm. Puts sampler within 10 cm of rock. Pushes sampler down with controlled force. Drives forward until sharp change in sampler force indicates contact. Raises sampler while driving forward to maintain correct ratio of sampler and drive forces. Senses release of forces, drives backward and makes pictures.

44. SR Gamma Spectrometer

Initiate long-term data accumulation only after total count-rate is below the RTG interference level.

45. SR Gamma Spectrometer

In the event background increases to a statistically significant extent, initiate timed sequence of spectra accumulation and dumping (e.g., solar flare event detection).

46. Deployed Seismometer

Same as 34, 35, 36, 37, and 38.

47. Neutron Activation

Frequency of spectral dumps determined by rate of signal decay, to provide adequate half-life determinations without excess data accumulation and storage.

48. Neutron Activation

Adaptively adjust source exposure period to attain response at some predetermined level above background.

49. Medium Rover (MR) Drill

Same as 8.

50. MR XRFS

Same as 14, 15, and 40.

51. MR Meteorology

Same as 31, 32, and 33.

52. Organic Sieve

Terminate analysis as soon as positive indication of yes or no on organic content. This allows maximum number of analyses for the limited supply of consumables.

53. Lander Camera

Measure atmospheric absorption and scattering properties during the day (hazes, clouds, etc.) by tracking and scanning Sun direction for direct brightness and aureole characterization. Include in computer memory the profile for a "nominal" day and look for changes. May be particularly effective at sunrise and sunset.

54. Lander Camera

Track as in 53 above to determine night time haze and cloud activity.

55. Lander Camera

Search for clouds and for changes in the terrain. Take time-lapse pictures of clouds and detailed pictures of changed terrain areas.

This mode is described in detail and evaluated in Volume II.

Benefits Routine sky pictures can not be taken often enough to be sure of recording clouds. Time lapse series are out of the question unless clouds have been detected.

The remaining reactions involve multiple instruments.

1. Wind Sensor - Lander Camera

When wind exceeds a set threshold, pan the camera lens from downwind direction to $\pm$ 90° from downwind. This provides pictures of wind-blown material with minimum damage to lens. Early in the mission always place the camera in the stowed position when wind is excessive.

Benefits Records data on windstorms not otherwise available while reducing danger of damage to camera windows.

2. Wind Sensor - Surface Sampler

Use wind velocity vector to prevent boom operation during possible dust storm. Also, when transferring sample, do so only when wind is below a predetermined value.

3. Rocket Launcher

If cloud detected, determine coordinates, aim rocket, and launch. Attempt measurement of meteorological parameters through cloud.

4. Wind Sensor - Rocket Launcher

When wind conditions are appropriate, launch rocket with smoke puffs for upper winds tracking.

The adaptive system can assure that best results are achieved by triggering the launch when wind, temperature, sunlight, and time of day are just right. The human team on Earth would make the decision to launch and give a command to be executed at the next time that conditions are within specified tolerances.

Launch by direct command would have to rely on good weather forecasts for Mars.

5. Lander XRFS - ABS - XRD

Since the ABS and XRD are slow, high-energy-consumption analyses relative to the XRFS, use the XRFS data to decide if a sample is very similar to one already analyzed. If so, may decide to bypass ABS and XRD measurements.

6. Integrated Geology - Wind Sensor - Sampler Boom

If wind is strong enough and from the proper direction, position the sampler head next to the integrated geology acceptance funnel and use as a deflector to collect wind-blown material for analysis.

7. Lander Camera - DSC/EGA

Using search mode for camera, look for frost formation on soil surface. If detected, attempt to collect a sample (boom or rover) for analysis by the DSC/EGA instrument.

8. DSC/EGA Integrated Geology

A sample showing a different quantity of water of crystallization from previous samples has high priority for analysis by the integrated geology.

9. DSC/EGA - Meteorology - Sampler Boom

Desire one sample at coldest part of the night to test for maximum condensed component. Likewise, desire sample at warmest part of the day for comparison.

10. Seismometer - Lander Mechanisms

When a significant event is detected, inhibit all lander mechanisms except those required for survival.

11. Seismometer - Wind Sensor - Lander Mechanisms

Periods when wind speed is low and when the lander is mechanically quiescent are high priority periods for acquisition of data on seismic noise background.

12. Seismometers - Seismic Source

Use seismometer to detect when noise is sufficiently low for conducting the active seismic experiment, i.e., set-off the source on the basis of low outputs from the seismometers.

13. Lander Camera - Rover Camera

Upon detection of targets of interest (e.g., albedo patches, clouds, etc.) direct the rover to a position for optimum stereo baseline, aim both cameras, and take pictures simultaneously.

14. Neutron Scatter - Rover Guidance

When backscatter maximum is detected, rover enters systematic search mode of traversing the area to seek water maximum.

15. Rocket/Balloon

Track rocket plume (or released chemicals) or balloon using the lander and rover cameras. Adaptively follow the dispersion. Size the picture and picture-taking frequency.

16. Organic Sieve - Wet Chemistry - Adv. Biology

Save data on organic sieve measurements and compare new results with old. If a sample has significantly higher organic content, take extra material, make beeline for lander, signal ground control at first opportunity, and deliver material to wet chemistry and advanced biology instruments for analysis.

17. Neutron Scatter - DSC/EGA

If anomalously high hydrogen content detected, attempt to return with sample to lander in short order and transfer to DSC/EGA for analysis.

18. Rover XRFS - Organic Sieve - Neutron Scatter - Trays

Use the data from the XRFS, organic sieve, and neutron scatter to evaluate the relative novelty of samples, and hence whether to discard or save in trays.

19. Rover TV - Gyro/Clinometer/Odometer

Take TV pictures each time rover has advanced by some nominal distance. When inclinometer readings indicate a new summit has been reached, take panoramic picture.

REFERENCES

1. R. B. Blizard: *Autofocusing Scanning Microscope*. Martin Marietta Report S-72-43554-17, 19 May 1972. Also "Addendum", December 1972.

V. ADAPTIVE-CONTROL SYSTEM

This chapter describes an adaptive control system that is suitable for a Mars lander with or without a rover. Three levels of control are used. The lowest level is concerned with the operation of individual experiments or subsystems and is embodied in software packages called "operating routines." Some of the operating routines are simple, such as the one for controlling a sequence of meteorological measurements. Others are more complex and may involve adaptive features--rover guidance with hazard avoidance is an example.

The next level of control is performed by the "executive controller." The executive controller determines which routines will be active at a particular time, and it is therefore the part of the system that decides when to perform all the scientific and engineering tasks. The success of the mission will depend on how well it performs this function.

Control at the top level is, of course, exercised by the teams of scientists and others on the Earth. Since there is little control over the design of this most important part of the adaptive system, it must be accommodated with an interface that permits it to operate with top efficiency.

Section A discusses the objectives of the system design and the general approach. Sections B and C describe the executive controller and the operating routine structure in detail. Section D tells how the computer requirements for the adaptive system were determined.

A. OBJECTIVES AND APPROACH

1. Objectives of an Executive Controller

Consider first what characteristics are desirable in an executive controller.

a. Flexibility - The controller must be easy to modify at any time until the end of the mission. During the period before landing, scientists and others will continue to get good ideas on how to improve the adaptive system. Unless great flexibility has been designed into the system from the beginning, it will be necessary to freeze the program at some relatively early time, and the benefit of later thought will be lost and creative people frustrated.

After landing, many changes will be desirable to adjust to actual conditions and discoveries.

b. Scope of Control - It is impossible to predict all the types of interactions and the modes of control that will become desirable during a mission. Therefore we want to be able to program the controller to start and stop any operation in response to any reasonable function of the scientific and engineering data that are being gathered as well as commands from Earth. If the system is designed so that the computer has access to all the data generated on board, planning and software design become easier because it is not necessary to decide in advance what data will be used to control each function of the landed system. Viking will give a lot of information about two landing sites, but these may be very different from the place where a later lander touches down. Scientific discoveries are obviously unpredictable and may greatly change the mission priorities. Performance of the various engineering and scientific systems is also uncertain--

scientific equipment can fail partially or totally, optical devices can be degraded by dust and abrasion, rovers can perform better or worse than expected because of soil properties and the lower Martian gravity, and the available power may be near the top or bottom of the predicted range of the power system. Adjustment to these uncertainties can and should be made from Earth by modifying the stored programs in the on-board computer.

c. Man-machine Interface - The executive controller interfaces intimately with the people who run the mission. It is the principal set of controls that they will use to make the landed system do what they want, and it is important to make it easy to understand and use. It should also reduce the amount of tedious work required for scheduling the many different operations that the lander and rover will perform.

The responsibility for controlling the mission is divided between scientific and mission operations teams. The scientists optimize the scientific return, and the operations team must assure the safety of the mission. The organization of the executive controller should reflect this division, and the science team should be able to change the emphasis and operation of the various scientific experiments without the risk of inadvertently jeopardizing the success of the whole mission. Elaborate cycles of approval and verification should be avoided so that scientific decisions can be made and executed in a short time.

d. Increasing Autonomy as the Mission Progresses - The system should be able to perform with varying degrees of autonomy. At the start of a mission almost all operations will be by direct command or predetermined sequence. During this period the system will be checked out, the environment in the immediate vicinity of the lander will be assessed, and detailed scientific objectives will be reviewed and modified to take advantage of the first findings. Rover performance on the Martian surface will be checked. The diurnal temperature cycle will be established, and the basic soil composition will be determined. Using the first panoramic pictures, the human team will plan safe initial sorties. As confidence is established in the system's ability to make good decisions and in the operation of hazard avoidance and other routines, more autonomy will be granted to increase the rates of exploration and sample taking.

Toward the end of the mission, the region close to the lander will have been thoroughly explored, and the rover may be sent on long excursions, even out of communication range, since the chance of finding something new will be worth the risk of losing the rover.

2. Approach

Figure V-1 shows the overall organization of an adaptive system which allows two groups of ground controllers, the science team and the mission operations group to exercise control over a single set of science and engineering hardware almost independently of each other. As can be seen from this figure, the science team's input to control is in terms of priority--"How much do we want to do this action?" The mission operations input is in terms of feasibility--"Is it safe for the total mission if this action is allowed?"

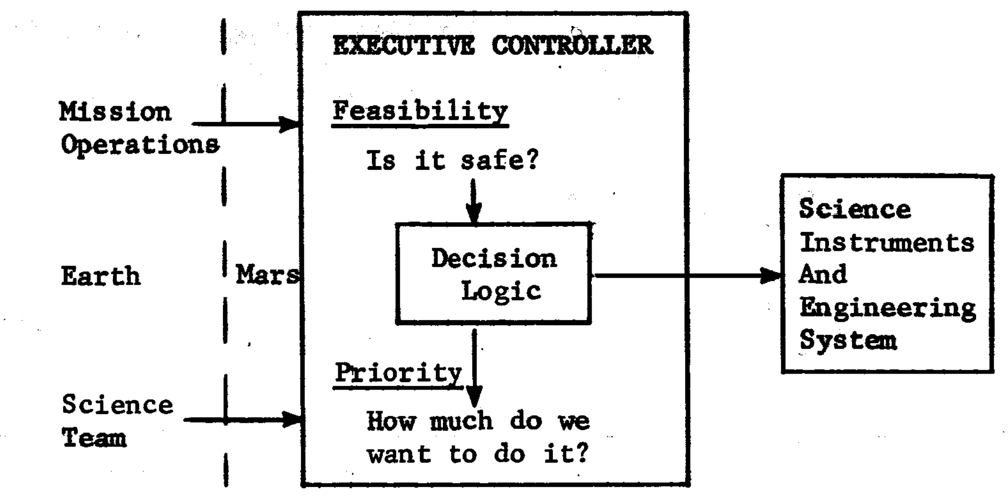


Figure V-1 Executive Controller Approach

a. Operation - At regular intervals, say once a minute, the executive controller makes up a list of things to do during the next minute. The choice of activities is based on priority and feasibility.

Priority is a numerical index of the desirability of doing each thing at the present time. The equations that determine priority are the responsibility of the science team. Typical items in the priority equation are listed here:

Continuity. An action that has been started but is not complete will get an increment in its priority proportional to the importance of not interrupting it.

Distance travelled or time since last action. Many activities, e.g., weather measurements, soil analysis, and panoramas should be done at more or less regular intervals. A component of priority that increases with time or distance since the last operation will give sufficient regularity without requiring a fixed schedule that could prevent response to transients or discoveries.

Difficulty in mobility. If the rover is unable to get around a hazard in a certain number of tries or if it encounters other serious problems, the priority of taking a panoramic picture should be raised enough to assure its prompt selection.

Interesting discovery. For example, a change in soil type, detected as a change in propulsive effort or by other means, would greatly increase the priority for taking a sample.

Weather. A high wind should alter the priority equation for sampling the collector of atmospheric dust.

Time of day. A search for clouds will probably have higher priority in the afternoon although it is conceivable that afternoon clouds may turn out to be commonplace in which case emphasis can be shifted to the morning hours by revising the priority equation.

Commands. The actions of the landed system can conveniently be controlled by issuing commands through priority changes. The priority of a particular action can be increased (by command from Earth) to a value higher than can be reached by any other action so that it is sure to be chosen as soon as its feasibility equation is satisfied. Alternatively, a somewhat lower priority can be assigned which will assure that the equipment is turned on providing that its feasibility conditions are met and that some unusual circumstances have not occurred. The unusual circumstances would be due to transient events such as engineering or environmental changes. An instrument can be permanently turned off by making its priority unconditionally equal to zero.

Feasibility is computed as "yes" or "no". The yes answer means that the action can be taken without violating rules set up by the mission operations team. Typical items in the feasibility equations include available power, ambient and internal temperatures, wind speeds that endanger camera lenses, and hazards to a rover. Conflicts between actions can also affect feasibility--it is not feasible to make a picture with a fax camera on a rover while it is in motion. If some action must be prevented, perhaps because of equipment failure, the feasibility equation can be modified from the Earth to give an unconditional "no".

b. Organization - Figure V-2 shows the overall organization and interface between the controlling computer and the lander/rover hardware.

A status array, which is accessible by both the lander/rover hardware and by the various computer subroutines, forms a major portion of the interface. This status array contains numeric values which have one or more of the following functions.

- constants
- input parameters used by operating routines to control their associated hardware
- outputs of the lander hardware used in the decisions of the executive controller
- values indicating the status of various engineering subsystems.

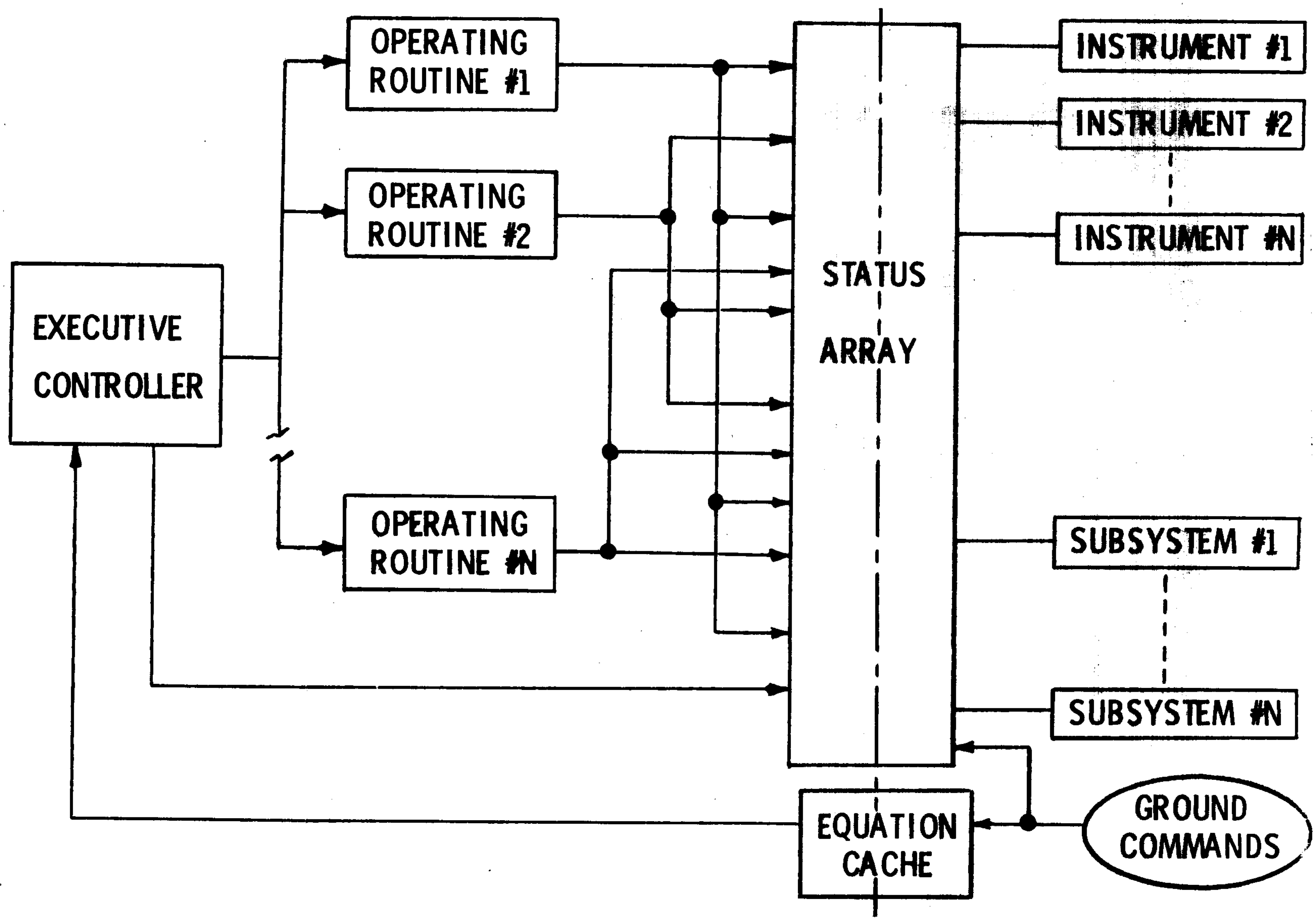


Figure V-2 Hardware/Software Interface

An equally important portion of the hardware/software interface is the equation cache which holds the equations by which the executive controller determines the priorities and feasibilities for the various possible actions.

Both the status array and the equation cache are easily changed by ground command which then provides the human interface.

B. EXECUTIVE CONTROLLER

Figure V-3 displays the overall block diagram for the executive controller which was developed during the course of this contract and which was also used in the system simulation shown in Chapter VI. A detailed description is given in Appendix A of this volume. The present version of this controller performs numerous input/output functions which will not be required in the operational program. The present controller size is used in estimating the required computer capabilities without making allowance for these surplus functions in order to provide a conservative result.

1. Main Executive Controller Program

The first block of Figure V-3 is entitled "Read/Write of Input Data" and represents the function of initial loading of the computer memory prior to liftoff. A portion of this memory was described as the status array in Section A. Other sections of input data read in at this time are the priority and feasibility equations which govern the interactions between the various operating routines. After initialization, the system enters a cyclic mode where each computer loop relates to the actual mission cycles being simulated.

The system operates on a dual cycle scheme in which a fast monitor cycle (about every second) samples those operating routines which have been identified as having a fast time constant. In addition, a configuration cycle (about every minute) determines the set of active operating routines for the next configuration cycle. An example of an operating routine which must be sampled each monitor cycle might be one which controls the motion of a

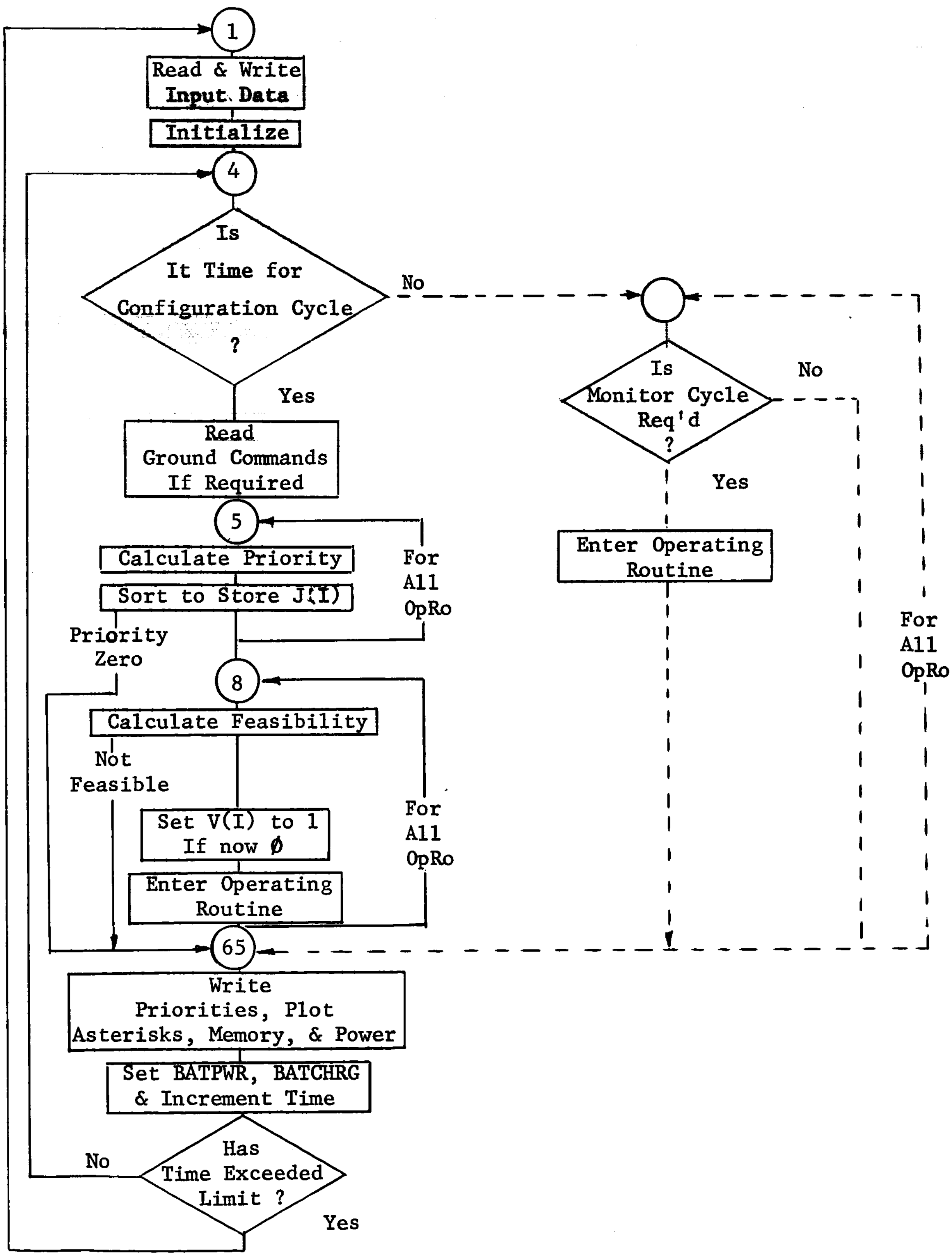


Figure V-3 Executive Controller Block Diagram rover. The rover performance can be increased by using the computer to determine hazardous conditions. However, the computer must have access to the rover sensors often enough to limit rover travel to 1 to 2 centimeters between hazard checks. This same 1 to 2 centimeters also determines the positional accuracy for the rover.

At the start of each mission time interval, a test is made to determine if it is time to start a configuration cycle. When a configuration cycle begins, all priority equations of the system are evaluated and the results are sorted into descending order. Then the feasibility equations are evaluated in the order just determined, highest priority first. As an operating routine is found to be feasible it is placed on an active components list. Sooner or later further additions to this list are found to be unfeasible because of power or memory constraints. Figure V-3 shows that by-passes are provided for those operating routines which either have a zero priority or which are found to be unfeasible. No additions can be made to the active list until the start of the next configuration cycle, although deletions can be made during monitor cycles.

For those components which are to be sampled each monitor cycle, it may be determined that an experiment should be terminated during the course of the configuration cycle. For example, the wind might rise to a high value requiring the covering of optical surfaces before the next configuration cycle.

The portion of Figure V-3 which is concerned with the monitor cycle was not actually programmed in the present version of the program and is therefore shown in dashed lines.

2. INLOG - Ground Command Decoder

In order to facilitate changing of the interrelationship between the various operating routines, the priority and feasibility equations are stored, transmitted and used as a group of binary bits. Therefore, even the most complicated equations can be completely changed in 8 seconds of the 4 BPS command uplink. In addition, individual values in the status array may be easily changed by transmitting a similar binary command to the lander. The general format arrangements for these two types of transmissions are shown below:

a. Equation Format

1	bits 2-8	bits 9-13	bits 14-23	bits 24-33	- - - -
	index of concerned component	number of 10-bit blocks to follow	up to 31 10-bit blocks		

b. Ground Command Format

10000000	bits 9-13	bits 15-23	bits 24-37	bits 38-51	bits 52-65
ground command indication	code of value meaning	index of concerned component	three possible values		

A subroutine INLOG is used to read and decode input equations and ground commands since this function is called for in two different places in the main program. Figure V-4 is a block diagram of this routine. Following the first bit (which is used to indicate the end of transmission when it has a value of zero) the next seven bits are decoded into an equation index which indicates the sepcific routine to which the particular equation is associated. When this index is zero the transmission

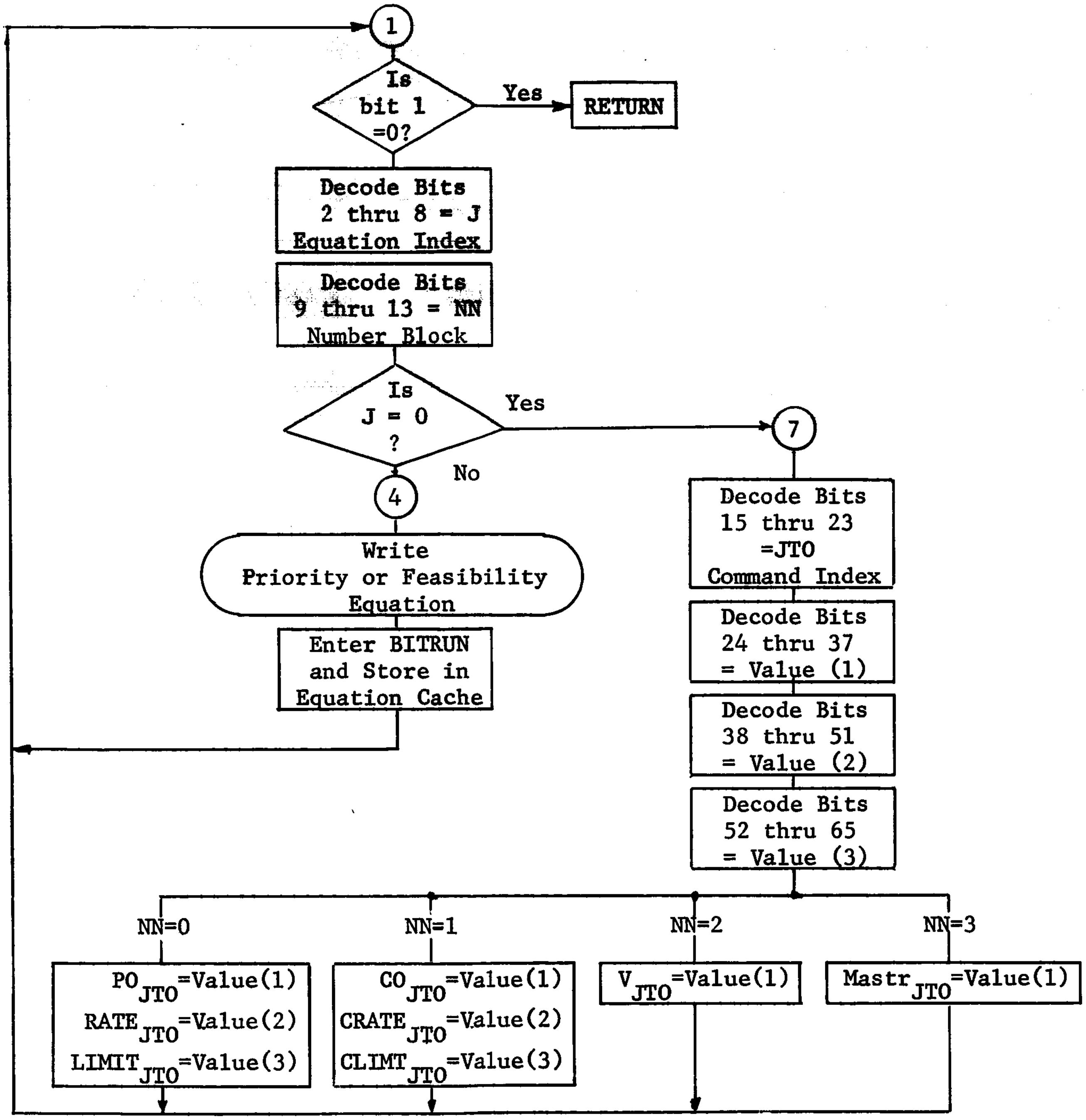


Figure V-4 Subroutine INLOG Block Diagram is not an equation but rather a ground command, indicating a change in a particular value in the status array. In Figure V-4, the branch starting with statement 4 is applicable if $J \neq 0$ and the command is a change in either a feasibility of a priority equation; or the branch starting with statement 7 is applicable if $J = 0$, for a commanded change in the status array.

Bits 9 thru 13 are decoded to an integer which either is the number of 10-bit words in the equation to follow or a code which designates the meaning of the change to the status array. In the case of equations, the bit array of the ground command is stored as a series of 20 digit octal numbers and for the status array change the applicable values are stored in the proper locations in the array.

Appendix A contains a detqiled description of the subroutine INLOG.

3. LOARG - Equation Evaluator

A subroutine LOARG is used to evaluate both feasibility and priority equations. This subroutine is called in three different places in the main program. The evaluation of the two types of equations is carried out in the same manner except for the last step: after evaluating a feasibility equation, if the answer is greater than zero the result is set equal to 1 otherwise it is set equal to -1.

Figure V-5 is a block diagram of the subroutine LOARG. In the first box the equation is fetched from the equation cache and each of the 10-bit blocks which make up the equation is considered in turn. The first bit in each block determines the purpose of the block. If the bit is a one, it indicates an address in the status array; if a zero, it indicates an operator

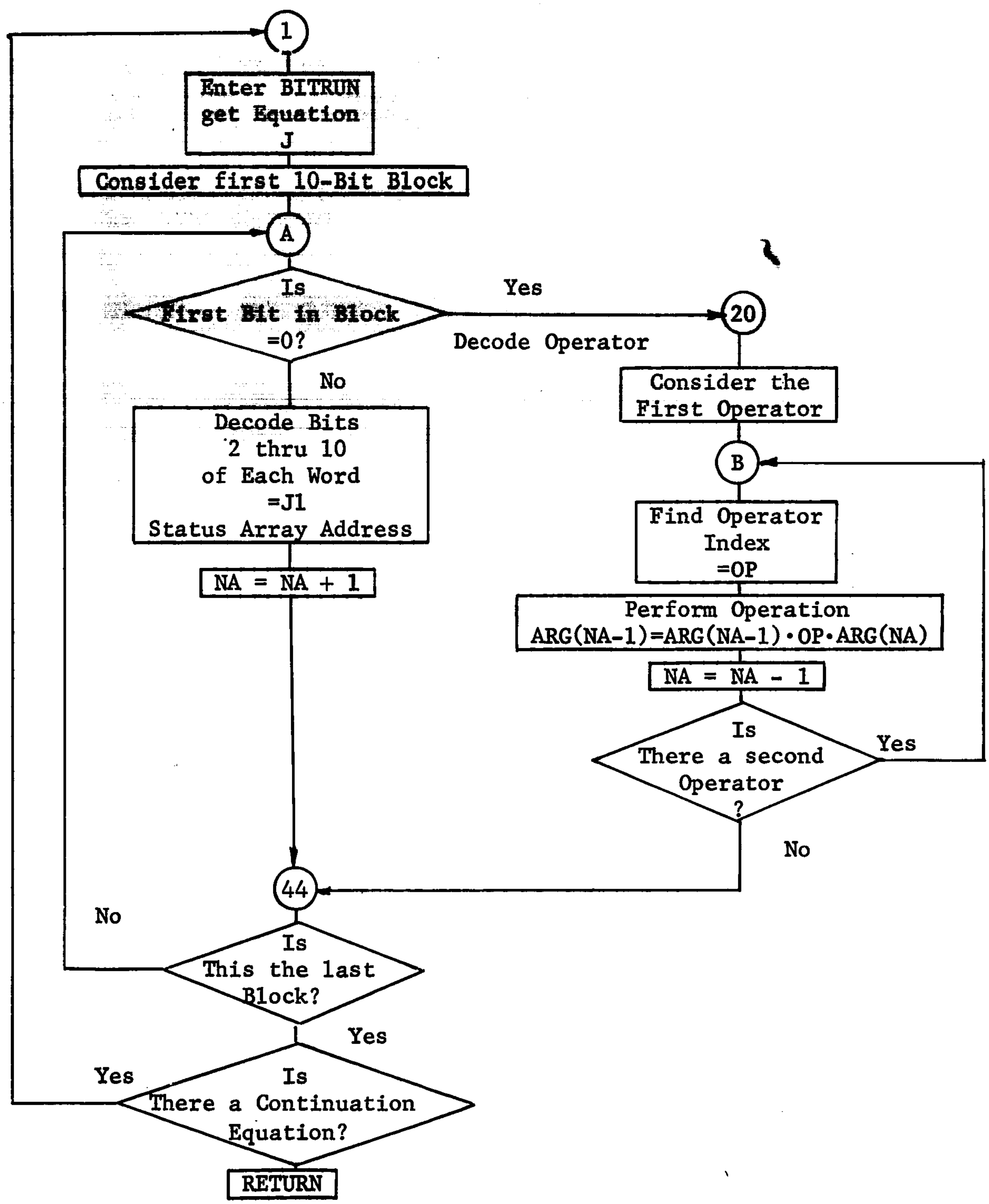


Figure V-5 Subroutine LOARG Block Diagram code. When the first bit is a one, the remaining 9 bits are decoded directly into one of 511 addresses in the status array and the number of arguments NA is incremented.

When the first bit in the block is a zero, the next 4 bits are decoded as one of 15 possible operator codes, and the appropriate operation is performed between the previously stored arguments. After this operation is performed, the result is stored and the number of stored arguments, NA, decremented. Since the 15 possible operator codes only require four bits for coding, bits 7 through 10 are then examined to decode a second operator.

Table V-1 lists the operators which have been identified for use. It should be noted that codes 12, 13, and 14 have not been assigned and that further, the operators 7, 8, 10 and 11 are not performed between two previously stored arguments and therefore the number of arguments is not decremented after their use.

The general form of the feasibility and priority equations is termed Polish notation which differs from normal algebraic notation in that no brackets are required. As used in this program, an equation is read from left to right storing each successive variable in a "push-down stack" until an operator is read. The operator is applied between the two variables at the top of the stack (except in the case of the operators 7, 8, 10 and 11). The answer is then re-stored in the stack, so that one less variable (or argument) is now contained in the stack. In the example shown below, the Polish equation is read in from the right a symbol at a time, and the contents of the push-down stack are shown on the left. If the proper number of operators is provided, the evaluation of the equation is the only content of the push-down stack when the equation is completely read in.

Table V-1 Equation Operators

Type	Operators	Symbol	Code	Remarks
Arithmetic	Multiply	A x B	0001	
	Addition	A + B	0010	
	Division	A ÷ B	0011	
	Subtraction	A - B	0100	
Boolean	AND	A ∩ B	0101	The lesser of A and B
	OR	A ∪ B	0110	The greater of A and B
	NOT	$\bar{A}$	0111	Minus A
Special	Equal	A =	1000	=1 if A=J or =-1 if A≠J where J is the index of component
	If	A If B	1001	=1 if A≥B or =0 if A<B
	P	A p	1010	Evaluates priority equation at A
	C	A c	1011	Evaluates continuity equation at A
	Set	J = A	1111	Sets the index of the equation equal to previously stored value A. In this way equation A is treated as a continuation of the last equation.

Push-Down Stack			Equation to be Read
			A B C - D + *
		A	B C - D + *
	A	B	C - D + *
A	B	C	- D + *
	A	(B-C)	D + *
A	(B-C)	D	+ *
	A	(B-C)+D	*
		A*[(B-C)+D]	

4. Bit Run - Bit Compressor

Since the executive controller is programmed in Fortran rather than in the computer assembly language, each of the bits which makes up a feasibility or priority equation must be given a separate 60-bit storage location in order that the individual bits may be treated separately. Reserving a 322 word array for a single equation uses considerable memory, but the total equation cache must have room for two such equations for each of a maximum of 63 operating routines (40,572 60-bit words). Entry point SETBIT of this routine packs the 322 possible bits into six 20-digit octal numbers for each equation. These six words for the 126 allowed equations plus the 322 word array for the equation under consideration (1108 60-bit words) allows reduction in storage by a factor of 40.

Entry point GETBIT reverses the operation to load the 322 word array with bits from the six 20-digits octal numbers. The 322 word array is labeled L(322) and the octal equation cache is labeled CACHE(6,163). The dimension of 163 stems from a convenience where the priority equations have the indexes 1 through

63 and the comparable feasibility equations the indexes 101 through 163.

A complete listing of BITRUN is given in Appendix A.

5. Typical Equation

In order to provide insight into the formation and use of the feasibility and priority equations, an example of an equation used in the system simulation is given below. First an English version of the equation conditions is formed, and the numerical quantities (variables) are either arbitrarily assigned locations in the status array or their previously assigned locations are determined. The next step is to form a normal algebraic equation using these addresses and the proper operators. This equation is then converted into Polish notation, the operators are coded, and the result written in binary form. Below this conversion is the set of octal digits which are stored in the equation cache.

English: The priority for high rate seismometry is the number stored in location V(450) when the seismic limit in V(58) has been exceeded or it is equal to the number stored in location V(449) if the index of the high rate seismometry is stored in location V(13) (commanded on).

Algebraic: [V(450) * V(58)] U [V(449) * V(13) =]

Polish: V(450) V(58) * V(449) V(13) = * U

Binary: 1 1 001 011 00111 1 111 000 010 1 000 111 010 0 0001 0 0000
1 111 000 001 1 000 001 101 0 1000 0 0001
0 0110 0 0000

7 words to follow

Index of High Rate Seismometer Operating Routine

Priority equation indicator

Octal: 62637606072020360301   52004600000000000000

two 20-digit words

C. OPERATING ROUTINES

The purpose of the operating routines is to operate the various science instruments and engineering subsystems. In general, these hardware components can be operated in various modes, and for the most part a different operating routine is programmed for each significantly different mode of operation. As a minimum, an operating routine will turn on the hardware and turn it off again when its function is accomplished. In the system simulation routines, the function of maintaining the power consumption and data memory bookkeeping is also performed by the operating routine.

The form and purpose of any specific routine is of course determined by its associated hardware. Chapter IV-A listed a large number (54) of adaptive reactions called the "single input class". In order for these reactions to be effected, programming must be provided in the specific operating routine, since these reactions are concerned with a single instrument and operating routine. The 20 examples of multiple input adaptive reactions are, of course, determined by the appropriate feasibility and priority equations. For the above reasons, actual operating routines can only be approximated in the absence of detailed instrument designs.

Figure V-6, Operating Routine Block Diagram, represents only those functions which must be performed by a minimal routine. Additional sequencing and programming to control single input adaptive reactions will normally be added into the box following statement 8 in the block diagram. The boxes entitled "Perform Turn-off Functions" and "Perform Turn-on Functions" normally are used to generate values for the status array which are required to control other operating routines.

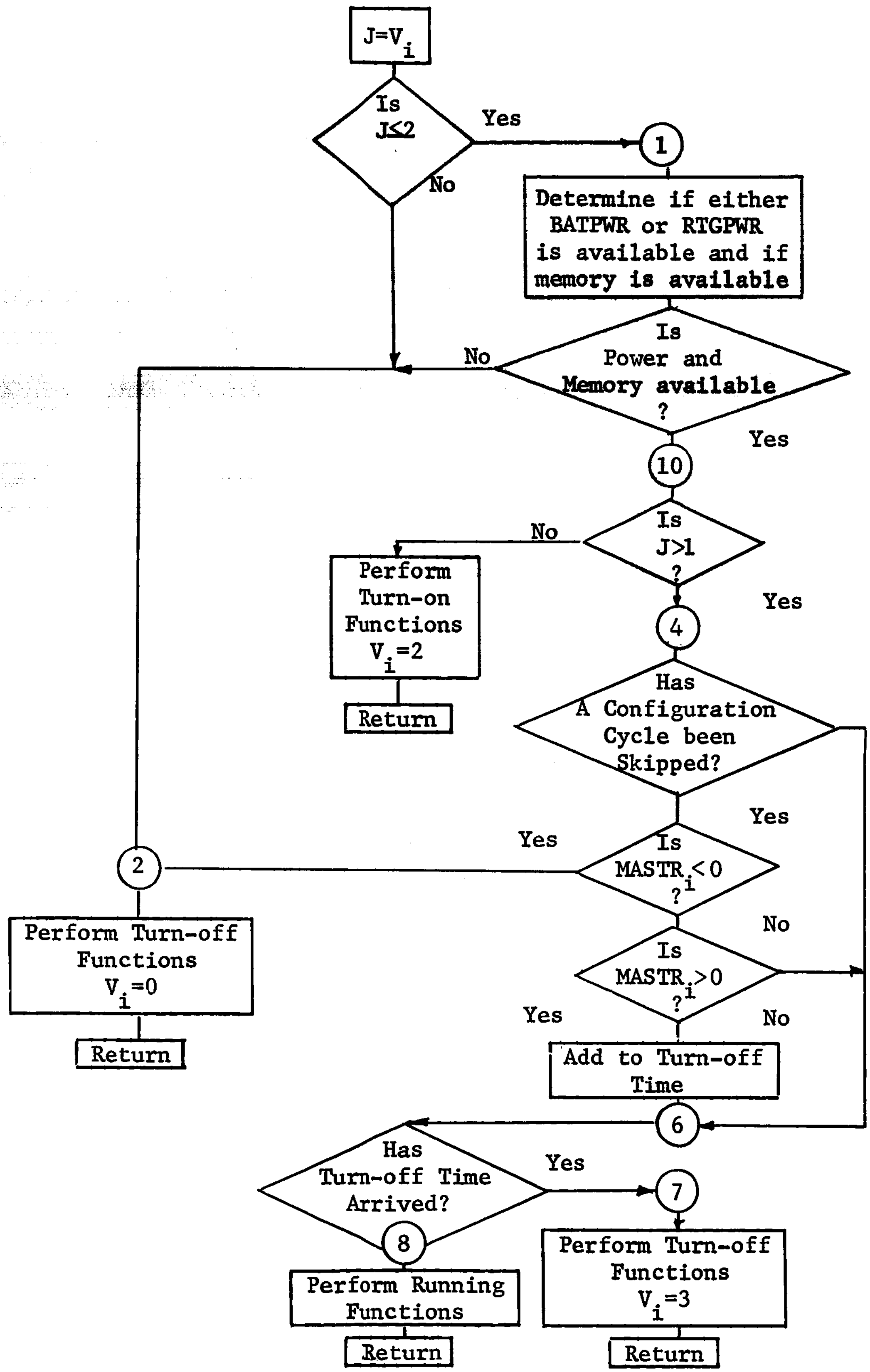


Figure V-6 Operating Routine Block Diagram

The network following statement 4 is useful when an instrument is interrupted during the normal course of its operation. The resulting action depends on a variable MASTR which in the event of an interruption and if its value is negative, terminates the experiment; if its value is positive, extends the shut-off time to provide the same duration or if it is zero, it ignores the interruption.

D. COMPUTER SIZING

Referring to Figure V-2, five main blocks of system programming can be identified: 1) the executive controller (including the subroutines INLOG, LOARG, and BITRUN); 2) the equation cache; 3) the status array; 4) a set of operating routines, and 5) computational routines. Each of these blocks may be sized in terms of their common denominator, memory words required. These memory words can either be data storage or programming instructions. The word size used is the 24 bit Viking GCSC computer word.

1. Executive Controller

The existing executive controller is programmed in Fortran on a large CDC computer where the programming word count is octal. The number of 60-bit instructions is first converted to decimal and then to the number of equivalent 24-bit instructions (by multiplying by 3.15 which is the experienced number of 15-bit and 30-bit instructions that can be loaded into a 60-bit word in a particular order).

	Number of Instructions		
Routine	60-Bit		24-Bit
	Octal	Decimal	Decimal
Control	422	274	860
INLOG	412	266	835
LOARG	452	298	936
BITRUN	71	57	179
			2810

2. Equation Cache

Sufficient capacity was provided for 63 different operating routines, each of which requires two equations, a priority and a feasibility--126 in all. Allowance was provided for 31 10-bit blocks, either status array addresses or operator codes, plus a 7-bit routine index and a 5-bit block count. The total size of the equation cache is then 322 x 126 = 40,572 bits, which is 1690 24-bit words.

3. Status Array

The nine-bit address for a location in the status array would provide for 511 variables. However, only the first 480 represent single values while the last 31 are the indexes of parameter arrays which provide a value for each possible operating routine. Since only 17 of these arrays were needed, the total status array required 1575 words of memory.

4. Operating Routines

The science complement of the lander and small deluxe rover were examined to determine what modes of operation would require separate operating routines. A similar examination was given to engineering subsystems. Each identified routine was then estimated as to complexity and the required number of programming words obtained. The estimations were based on the minimal operating routine described in Section C and on the number of desired adaptive reactions. Tables V-2 and V-3 list the operating routines and their memory requirements for the lander and small rover.

Table V-2 Sizing of Operating Routines - Lander

Instrument	Routine	Memory
Facsimile Camera	# Cloud Search	168
	# Rover View	50
	# Specific View	350
	Motion Detector	360
	Aerosol Detector	150
Surface Sampler	Sample Pick-up	100
	Dig Trench	250
	Surface Profile	350
Drill	Feed Rate Control	288
Integrated Geology		
XRFS	Operation	200
	Sample Sort	Routine A
ABS	Operation	210
XRD	Operation	250
Water Detector	Operation	225
Advanced Biology	Operation	300+Routine A
Wet Chemistry	Operation	500
Meteorology	# Operation	200
	Detect Anomaly	288
	# High Data Mode	----
Seismometry	# Operation	225
	# High Rate Mode	----
Electrical Power	Battery Charge Control	200
Data Transmission	# Priority Assignment	300
	Antenna Control	150
Initial Deployment	Sampling Boom	50
	Meteorology Boom	50
	Rover	50
Total		5264

Table V-3 Sizing of Operating Routines - Small Rover

Instrument	Routine	Memory
Control Limit Set	MUCAL	157
Hazard Identification	HI	55
Hazard Avoidance	HA	34
Guidance Calculation	NAV	152
Sampling Control		157
Misc Storage & Subroutines	DSC, ARMCTL, & CVLN	135
	Standard Small Rover	690
Television	# View Ahead # Panorama Rock Finder	350 --- Routine B
Drill	Control	288
Gamma Spectrometer	Operation	200
XRFS	Operation Proximity Survey	200 --- Routine A
Seismometer	Operation	200
Total Deluxe Additions		1238

Notes: The routine marked with a # in the table above are included in system simulation described in Chapter VI.

The routines A and B shown in Tables V-2 and V-3 are computational routines which are described in the next section and are not counted as a part of the operating routine memory requirements.

The memory requirements for the control of the standard small rover are described in "Small Rover Mobility and Sampling Control Requirements," by C. E. Farrell, Martin Marietta Technical Note, February 1973.

5. Computational Routines

Many mathematical operations will be of general use in various operating routines and therefore memory space can be better utilized if these operations are programmed as subroutines callable by more than one operating routine. Two large routines are described in the appendixes; a sample screening routine in Appendix D and a routine for finding surface rocks in an image in Appendix E.

6. Sizing Summary

The following blocks of programming and data storage have been allocated or estimated:

Use	Words
Executive Controller	2810
Miscellaneous Variables	400
Equation Cache	1690
Status Array	1575
Operating Routines	
Lander	5264
Small Rover - Standard	690
Small Rover - Deluxe Additions	1238
Computational Routines	
Routine A - Sample Screening	1390
Routine B - Rock Sample Locator	200
	15257

It should be noted that the operating routines which would be required by the medium rover have not been estimated. For the safety of the rover which will be operating at great distances from the lander, it has been assumed that the rover will carry its own computer which should be smaller in requirements than the lander/small rover combination.

The number of words of computer memory required is to be compared with the present Viking GCSC computer memory of 20480 words only 18432 of which are available for programming use. Approximately 6000 words of this memory are being used for purposes beyond the scope of this study; for example, control of the terminal descent engines. In order to use the present concept on the present computer, one of two possible actions would be necessary: 1) the adaptive programming must be stored on the tape recorder and loaded into the computer memory after landing is completed, or 2) the computer memory must be expanded toward the maximum memory addressable by the computer word structure of 32768 words.

An additional change must be made; the present Data Acquisition and Processing Unit (DAPU) which has the functions of providing intermediate data storage, sequencing the tape recorder, and controlling data must be replaced. One possible alternative is a new unit which contains the additional memory and circuitry to control the tape recorder while the computer itself controls the data acquisition. In any event the computer must have access to the data being generated by the various science instruments and engineering subsystems in order to base decisions on this data in an adaptive manner.

VI. ADAPTIVE SYSTEM SIMULATION

In order to check out the operation of the executive controller and the general system concept, a realistic portion of the operating routines which would be required by a lander and a small deluxe rover were programmed and appropriate controlling equations and status array values provided. Appendix C gives a detailed listing of these inputs and conditions. The size of the system was picked to provide an interesting, yet simple simulation.

Figure VI-1 displays the assumed configuration consisting of 12 operating routines. The instruments include a rover camera, the lander cameras, and the integrated meteorology system. In addition, rover motion and data transmission are considered. All instruments operate in more than one mode, but only in one mode at a time. Each operating mode requires a separate operating routine to facilitate switching between modes. The principal transient events which control the sequencing of these instruments are indicated. A cloud search routine, upon detecting a cloud, activates a camera mode which takes a TV view of the cloud. The seismometer and meteorology experiments can switch themselves into high data rate modes when unusual measurements are taken. The rover on detecting a hazard to its motion, signals its camera to take a panorama of its surroundings which in turn calls for a TV view of the rover from the lander camera.

Other interactions not shown include the inhibiting of the rover motion and the lander camera while the seismometer is in its high data rate mode, covering the two camera lenses when the wind exceeds a given value, stopping the rover motion when the wind exceeds another set value, inhibiting camera operation

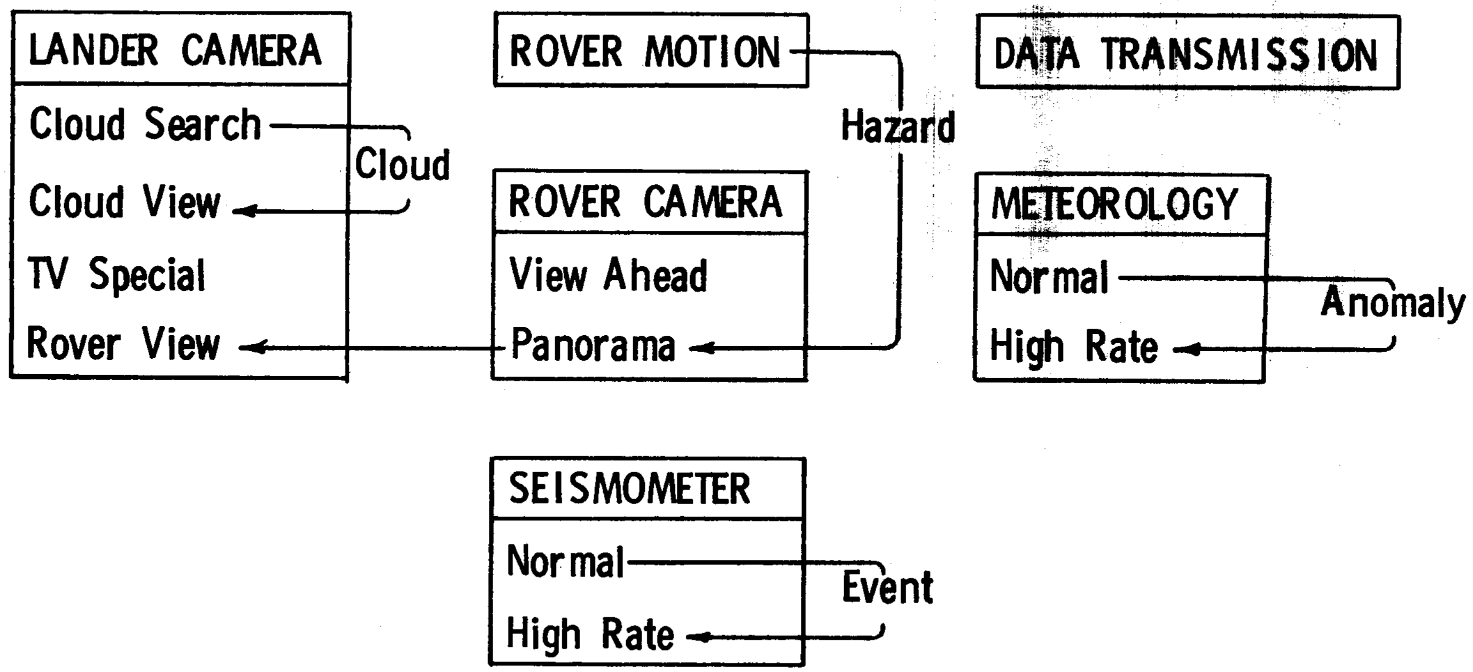


Figure VI-1 Configuration of System Simulation except by ground command during darkness, making the rover camera priorities a function of the distance the rover has travelled, and constraining the system activity within power and memory limits.

A random number generator is used to inject "events" such as hazards to the rover, weather changes, and seismic events. The following pages show some of the scenario that has been obtained in the form of computer print-out.

Each of the 12 routines is represented by a column in the print-out.

METEOROLOGY is the regular mode of gathering weather data.

The HI DATA METEOR mode is turned on when the weather is more interesting than usual. In this mode the meteorological instruments are sampled more often to record detailed dynamics of weather changes.

CLOUD SEARCH is a way of using the imaging system to make a quick check of the sky to see whether clouds are present. In the CLOUD VIEW mode the imaging system takes pictures where the clouds were detected.

ROVER VIEW is a picture of the rover taken from the lander. ROVER PANORAMA (column 9) is a 360^{o} view from the rover camera. Both of these modes are useful in deciding how to give commands from Earth to get the rover out of trouble if the on-board system is unsuccessful.

ROVER MOTION makes the rover proceed according to stored instructions that have been provided by command from Earth.

For TV VIEW AHEAD, the rover takes a picture of the scene ahead. It looks down as steeply as possible to record the details of the ground and looks up far enough to include some local landmarks. It is normally activated at regular short distance intervals (2.5 meters as programmed here) but of course it may be delayed if more urgent (higher priority) actions are required.

SEISMOMETER and HI RATE SEISMO are the low and high data rate modes.

DATA XMISSION is the data dump to the orbiter. It normally occurs as soon as the orbiter is high enough over the horizon. Even this important action can be delayed by competing modes of operation if they have high enough priorities, although this does not happen in the following scenario.

Each page of print-out is keyed by a page of explanation.

THIS PAGE INTENTIONALLY LEFT BLANK.

SYSTEM SIMULATION - ROVER HAZARD DETECTED

In the format used to print out the condition of the simulated system, two lines of information are shown for each time period. The first lines give the time if it happens to be a multiple of five, and the priority of each of the twelve operating routines. On the second line are found asterisks below the priority of routines which are active, the total number of kilobits of data stored in the memory, the unused battery and RTG power after the time period. The time is given in minutes and the power in watts. Preceding the two lines of any time period are on occasion listings of data generated in the operating routines or commands issued by the ground during that time period.

Four routines are essentially free-running: meteorology, cloud search, rover motion, and the seismometer. Two of these routines, meteorology and seismometer, are on initially since there was no built-in delay for their operation. Since they draw 5 and 10 watts and the total RTG power is set at 42 watts, there is an excess of 27 watts shown for the first two minutes.

The following events of note occurred during the mission times shown:

1. At time = 722, rover motion is enabled with an initial priority of 10. Since power is available, the rover starts at time = 723.
2. At time = 725, excessive tension on the rover tether is detected and therefore at time = 726 the rover motion is interrupted and the rover camera starts a panorama to provide information for the ground command to determine the cause of the rover hazard.
3. At time = 731, the cloud search routine is enabled so that the priority starts its rise.

SYSTEM SIMULATION - ROVER HAZARD DETECTED

TIME	METEOROLOGY	HI DATA METEOR	CLOUD SEARCH	CLOUD VIEW	TV SPECIAL	ROVER VIEW	ROVER MOTION	TV VIEW AHEAD	ROVER PANORAMA	SEISMOMETER	HI RATE SEISMO	DATA XMISSION	MEMORY STORED KBIT	EXCESS BAT PWR	EXCESS RTG PWR
720	75 *	0	0	0	0	0	0	0	0	20 *	0	0	0	10.0	27.0
	75 *	0	0	0	0	0	0	0	0	45 *	0	0	0	10.0	27.0
	75 *	0	0	0	0	0	10 *	0	0	45 *	0	0	0	7.0	0.
	75 *	0	0	0	0	0	40 *	0	0	45 *	0	0	1	7.0	0.
	75 *	0	0	0	0	0	40 *	0	0	45 *	0	0	2	7.0	0.
HAZARD DETECTED -ROVER TETHER TENSION IS .49															
725	75 *	0	0	0	0	0	40 *	0	0	45 *	0	0	2	6.9	0.
	75 *	0	0	0	0	0	40	0	60 *	45 *	0	0	18	9.9	8.1
	75 *	0	0	0	0	0	15	0	60 *	45 *	0	0	33	9.9	8.1
	75 .*	0	0	0	0	0	16	0	60 *	45 *	0	0	49	9.9	8.1
	75 *	0	0	0	0	0	17	0	60 *	45 *	0	0	64	9.9	8.1
730	75 *	0	0	0	0	0	18	0	60 *	45 *	0	0	79	9.9	8.1
	75 *	0	1	0	0	0	19	0	60 *	45 *	0	0	95	9.9	8.1

SYSTEM SIMULATION - METEOROLOGY AND CLOUDS

The following events of note occurred during the mission times shown:

1. At time = 734, the seismometer experiment times out (14 minutes) which allows power to be switched to the cloud search experiment which has a priority of 5. The rover motion with a higher priority is not turned on because of the 30 watts of power required. The priority of the cloud search experiment is raised to 55 once it is on to keep it on.
2. At time = 735, the meteorology detects an anomaly such as an unusual rise in temperature and the high data rate meteorology is turned on.
3. At time = 736, the cloud search experiment detects a cloud which provides a high priority to the cloud view experiment which turns on at time = 737.
4. At time = 741, the rover camera finishes its panorama which in turn enables the lander camera to take a view in the direction of the rover.
5. At time = 742, the turn-off of the rover camera frees power to enable the seismometer to turn back on. At the same time, the lander camera finishes its picture of the cloud, which allows the camera to swing around to make a view of the rover.
6. At time = 743, the lander camera starts taking a view of the rover.

SYSTEM SIMULATION - METEOROLOGY AND CLOUD

TIME	METEOROLOGY	HI DATA METEOR	CLOUD SEARCH	CLOUD VIEW	TV SPECIAL	ROVER VIEW	ROVER MOTION	TV VIEW AHEAD	ROVER PANORAMA	SEISMOMETER	HI RATE SEISMO	DATA XMISSION	MEMORY STORED KBIT	EXCESS BAT PWR	EXCESS RTG PWR
	75*	0	2	0	0	0	20	0	60*	45*	0	0	110	9.9	8.1
	75*	0	3	0	0	0	21	0	60*	45*	0	0	126	9.9	8.1
	75*	0	4	0	0	0	22	0	60*	45*	0	0	141	9.9	8.1
METEOROLOGY ANOMALY DETECTED															
735	75*	0	5*	0	0	0	23	0	60*	45	0	0	172	9.1	0.
CLOUD DETECTED															
	75	80*	55*	0	0	0	24	0	60*	20	0	0	203	9.1	0.
	0	80*	55	82*	0	0	25	0	60*	21	0	0	1178	9.1	0.
	0	80*	8	85*	0	0	26	0	60*	21	0	0	2154	9.1	0.
	0	80*	9	85*	0	0	27	0	60*	22	0	0	3129	9.1	0.
740	0	80*	10	85*	0	0	28	0	60*	22	0	0	4105	9.1	0.
	0	80*	11	85*	0	0	29	0	60*	23	0	0	5080	9.1	0.
	0	80	12	85*	0	0	30	0	60	23*	0	0	6040	9.9	13.1
	75*	0	13	85	0	70*	31	0	0	45*	0	0	7000	9.9	8.1

SYSTEM SIMULATION - TV FINDS CAUSE OF ROVER HAZARD

The following events of note occurred during the mission times shown:

1. At time = 748, the rover view is completed, and in an actual case some time, perhaps a whole orbiter period, would be required for the ground to determine the proper evasive action, In this simulation it has been assumed that this action takes no time so that in the next time period the rover is permitted to proceed.
2. At time = 749, the rover starts to move again.
3. At time = 751, the rover has not been on for a total of 5 minutes at a velocity of 0.5 meters per minute so that by this time the rover has gone over 2.5 meters since the last TV view ahead.
4. At time = 752, the rover is stopped and its camera starts to take a picture in the direction the rover is headed.

SYSTEM SIMULATION - TV DETERMINES CAUSE OF ROVER HAZARD

TIME	METEOROLOGY	HI DATA METEOR	CLOUD SEARCH	CLOUD VIEW	TV SPECIAL	ROVER VIEW	ROVER MOTION	TV VIEW AHEAD	ROVER PANORAMA	SEISMOMETER	HI RATE SEISMO	DATA XMISSION	MEMORY STORED KBIT	EXCESS BAT PWR	EXCESS RTG PWR
	75*	0	14	0	0	70*	32	0	0	45*	0	0	7361	9.9	8.1
745	75*	0	15	0	0	70*	33	0	0	45*	0	0	8921	9.9	8.1
	75*	0	16	0	0	70*	34	0	0	45*	0	0	9881	9.9	8.1
	75*	0	17	0	0	70*	35	0	0	45*	0	0	10841	9.9	8.1
	75*	0	18	0	0	70*	36	0	0	45*	0	0	11801	9.9	8.1
	75*	0	19	0	0	70	37*	0	0	45*	0	0	11802	6.9	0.
750	75*	0	20	0	0	0	40*	0	0	45*	0	0	11802	6.9	0.
	75*	0	21	0	0	0	40*	0	0	45*	0	0	11803	6.9	0.
	75*	0	22	0	0	0	40	46*	0	45*	0	0	11818	9.9	8.1
	75*	0	23	0	0	0	40	50*	0	45*	0	0	11834	9.9	8.1
	75*	0	24	0	0	0	40	50*	0	45*	0	0	11849	9.9	8.1
755	75*	0	25	0	0	0	40	50*	0	45*	0	0	11865	9.9	8.1

SYSTEM SIMULATION - HIGH WINDS STOP TV

The following events of note occurred during the mission times shown:

1. At time = 756, the seismometer completes a times sequence of 14 minutes and frees its power.
2. At time = 757, the cloud search TV mode is started on the lander. (Rover requires too much power.)
3. At time = 759, the cloud search routine detects a cloud which enables the cloud view routine.
4. At time = 760, the cloud view routine starts an image of the cloud which stops the cloud search.
5. At time = 762, the rover camera finishes its view ahead. At this time 18.1 watts of RTG power are available as well as 9.8 watts of battery power.
6. At time = 763, the seismometer with a priority of 23 is turned on instead of the rover motion with a priority of 40 because the motion requires 30 watts or instead of cloud search with a priority of 33 because only one lander TV mode is permitted at a time.
7. At time = 765, the meteorology experiment measures a wind in excess of the TV wind placard which interrupts the cloud view providing enough power to start the rover again.
8. At time = 767, the wind having died down allows the cloud search with a priority of 85 to resume interrupting the rover again.

SYSTEM SIMULATION - HIGH WIND STOPS TV

TIME	METEOROLOGY	HI DATA METEOR	CLOUD SEARCH	CLOUD VIEW	TV SPECTAL	ROVER VIEW	ROVER MOTION	TV VIEW AHEAD	ROVER PANORAMA	SEISMOMETER	HI RATE SEISMO	DATA XMISSION	MEMORY STORED KBIT	EXCESS BAT PWR	EXCESS RTG PWR
	75 *	0	26	0	0	0	40	50 *	0	45 *	0	0	11880	9.9	8.1
	75 *	0	27 *	0	0	0	40	50 *	0	45	0	0	11911	9.1	0.
	75 *	0	55 *	0	0	0	40	50 *	0	20	0	0	11942	9.0	0.
CLOUD DETECTED															
	75 *	0	55 *	0	0	0	40	50 *	0	21	0	0	11972	9.0	0.
760	75 *	0	55	82 *	0	0	40	50 *	0	21	0	0	12948	9.0	0.
	75 *	0	31	85 *	0	0	40	50 *	0	22	0	0	13923	9.0	0.
	75 *	0	32	85 *	0	0	40	50 *	0	22	0	0	14898	9.0	0.
	75 *	0	33	85 *	0	0	40	50	0	23 *	0	0	15858	9.8	8.1
	75 *	0	34	85 *	0	0	40	0	0	45 *	0	0	16819	9.8	8.1
WIND IS 3.26 M/SEC OVER LIMIT OF 3.00 M/SEC															
765	75 *	0	35	85 *	0	0	40	0	0	45 *	0	0	17779	9.8	8.1
	75 *	0	36	85	0	0	40 *	0	0	45 *	0	0	17779	6.8	0.
	75 *	0	37	85 *	0	0	40	0	0	45 *	0	0	18739	9.8	8.1

SYSTEM SIMULATION - METEOROLOGY ANOMALY

The following events of note occurred during the mission times shown:

1. At time = 772, the cloud view is completed, allowing the cloud search to resume.
2. At time = 774, the meteorology detects another anomaly, switching to its high rate mode.
3. At time = 779, the cloud search routine finishes its sequence.

SYSTEM SIMULATION - METEOROLOGY ANOMALY

TIME	METEOROLOGY	HI DATA METEOR	CLOUD SEARCH	CLOUD VIEW	TV SPECIAL	ROVER VIEW	ROVER MOTION	TV VIEW AHEAD	ROVER PANORAMA	SEISMOMETER	HI RATE SEISMO	DATA XMISSION	MEMORY STORED KBIT	EXCESS BAT PWR	EXCESS RTG PWR
	75 *	0	38	85 *	0	0	40	0	0	45 *	0	0	19700	9.8	8.1
	75 *	0	39	85 *	0	0	40	0	0	45 *	0	0	20660	9.8	8.1
770	75 *	0	40	85 *	0	0	40	0	0	45 *	0	0	21620	9.8	8.1
	75 *	0	41	85 *	0	0	40	0	0	45 *	0	0	22580	9.8	8.1
	75 *	0	42	85 *	0	0	40	0	0	45 *	0	0	23540	9.8	8.1
	75 *	0	43 *	85	0	0	40	0	0	45 *	0	0	23555	9.8	8.1
METEOROLOGY ANOMALY DETECTED															
	75 *	0	55 *	0	0	0	40	0	0	45 *	0	0	23571	9.8	8.1
775	75	80 *	55 *	0	0	0	40	0	0	45 *	0	0	23586	9.8	8.1
	0	80 *	55 *	0	0	0	40	0	0	45 *	0	0	23602	9.8	8.1
	0	80 *	55 *	0	0	0	40	0	0	45 *	0	0	23618	9.8	8.1
	0	80 *	55 *	0	0	0	40	0	0	45	0	0	23633	9.8	18.1
	0	80 *	55 *	0	0	0	40	0	0	20 *	0	0	23649	9.8	8.1

SYSTEM SIMULATION - SEISMIC EVENT RECORDED

The following events of note occurred during the mission times shown:

1. At time = 780, the high data meteorology timed out, and an excessive seismic level was measured, signaling a switch to the high rate seismic mode. During this minute, there was power to run the rover briefly.
2. At time = 781, the high rate seismometer inhibits the rover operation, even though power is available.
3. At time = 784, the high rate seismometer times out, allowing the rover to continue and switching the seismometer back to its normal mode.
4. At time = 790, the orbiter is high enough above the horizon and transmission of data to the orbiter is assigned a high priority. The power requirements of the data system shut off all other users. At this time, the data stored starts to decrease.

SYSTEM SIMULATION - SEISMIC EVENT RECORDED

```
                          ROVER VIEW   ROVER MOTION                 MEMORY     EXCESS
TIME                   TV SPECTAL  ↓   ↓   TV VIEW AHEAD            STORED   RAT   RTG
                    CLOUD VIEW  ↓   ↓   ↓   ↓  ROVER PANORAMA        KBIT    PWR   PWR
                CLOUD SEARCH  ↓   ↓   ↓   ↓   ↓   ↓  SEISMOMETER
     HI DATA METEOR  ↓   ↓   ↓   ↓   ↓   ↓   ↓   ↓  HI RATE SEISMO
     METEOROLOGY  ↓   ↓   ↓   ↓   ↓   ↓   ↓   ↓   ↓   ↓  DATA XMISSION
                  ↓   ↓   ↓   ↓   ↓   ↓   ↓   ↓   ↓   ↓   ↓   ↓
                SEISMIC LEVEL OF 15.799 EXCEEDS EVENT CUTOFF OF 10.000
780               0  80  55   0   0   0  40   0   0  45   0   0
                      *                   *           *
                                                                     23649   6.8    0.
                  0  80   0   0   0   0  40   0   0  45  90   0
                                                              *
                                                                     23651   9.8   30.0
                 75   0   0   0   0   0  40   0   0  22  90   0
                  *                                           *
                                                                     23654   9.8   25.0
                 75   0   0   0   0   0  40   0   0  22  90   0
                  *                                           *
                                                                     23656   9.8   25.0
                 75   0   0   0   0   0  40   0   0  23  90   0
                  *                       *           *
                                                                     23656   6.8    0.
785              75   0   0   0   0   0  40   0   0  45   0   0
                  *                       *           *
                                                                     23657   6.8    0.
                 75   0   0   0   0   0  40   0   0  45   0   0
                  *                       *           *
                                                                     23658   6.8    0.
                 75   0   0   0   0   0  40   0   0  45   0   0
                  *                       *           *
                                                                     23658   6.7    0.
                 75   0   0   0   0   0  40   0   0  45   0   0
                  *                       *           *
                                                                     23659   6.7    0.
                 75   0   0   0   0   0  40   0   0  45   0   0
                  *                       *           *
                                                                     23659   6.7    0.
790              75   0   0   0   0   0  40   0   0  45   0  95
                                                                  *
                                                                     23659   1.7    0.
                 75   0   1   0   0   0  40   0   0  26   0  95
                                                                  *
                                                                     22699   1.6    0.
```

SYSTEM SIMULATION - DATA TRANSMISSION

The following events of note occurred during the mission time shown:

1. For this whole time period the data transmission system is transmitting, using the whole power available.

SYSTEM SIMULATION - DATA TRANSMISSION

```
                       ROVER VIEW   ROVER  MOTION                    MEMORY      EXCESS
 TIME              TV  SPECIAL  ↓    ↓   TV  VIEW AHEAD              STORED    BAT   RTG
               CLOUD VIEW  ↓    ↓    ↓    ↓  ROVER PANORAMA           KBIT     PWR   PWR
           CLOUD SEARCH ↓   ↓    ↓    ↓    ↓   ↓  SEISMOMETER
  HI DATA METEOR  ↓    ↓    ↓    ↓    ↓    ↓   ↓   ↓  HI RATE SEISMO
  METEOROLOGY  ↓    ↓    ↓    ↓    ↓    ↓    ↓   ↓   ↓   ↓  DATA XMISSION
              ↓    ↓    ↓    ↓    ↓    ↓    ↓    ↓   ↓   ↓   ↓   ↓
             75    0    2    0    0    0   40    0   0  27   0  95
                                                                   *      21739    1.6   0.
             75    0    3    0    0    0   40    0   0  27   0  95
                                                                   *      20779    1.6   0.
             75    0    4    0    0    0   40    0   0  28   0  95
                                                                   *      19819    1.5   0.
 795         75    0    5    0    0    0   40    0   0  28   0  95
                                                                   *      18859    1.5   0.
             75    0    6    0    0    0   40    0   0  29   0  95
                                                                   *      17899    1.4   0.
             75    0    7    0    0    0   40    0   0  29   0  95
                                                                   *      16939    1.4   0.
             75    0    8    0    0    0   40    0   0  30   0  95
                                                                   *      15979    1.3   0.
             75    0    9    0    0    0   40    0   0  30   0  95
                                                                   *      15019    1.3   0.
 800         75    0   10    0    0    0   40    0   0  31   0  95
                                                                   *      14059    1.2   0.
             75    0   11    0    0    0   40    0   0  31   0  95
                                                                   *      13099    1.2   0.
             75    0   12    0    0    0   40    0   0  32   0  95
                                                                   *      12139    1.2   0.
             75    0   13    0    0    0   40    0   0  32   0  95
                                                                   *      11179    1.1   0.
```

SYSTEM SIMULATION - RETURN TO NORMAL

The following events of note occurred during the mission times shown:

1. At time = 810, the 20 minute period for transmission to the orbiter expires with 4,459,000 bits still in memory.
2. At time = 811, the three routines having the highest priorities are switched on; meteorology, rover motion, and the seismometer.
3. At time = 813, the rover has completed a travel of 2.5 meters since the last TV view ahead was taken, its motion is stopped to enable the camera.

SYSTEM SIMULATION - RETURN TO NORMAL

TIME	METEOROLOGY	HI DATA METEOR	CLOUD SEARCH	CLOUD VIEW	TV SPECIAL	ROVER VIEW	ROVER MOTION	TV	VIEW AHEAD	ROVER PANORAMA	SEISMOMETER	HI RATE SEISMO DATA XMISSION	MEMORY STORED KBIT	EXCESS BAT PWR	EXCESS RTG PWR
	75	0	14	0	0	0	40	0	0	33	0	95			
												*	10219	1.1	0.
805	75	0	15	0	0	0	40	0	0	33	0	95			
												*	9259	1.0	0.
	75	0	16	0	0	0	40	0	0	34	0	95			
												*	8299	1.0	0.
	75	0	17	0	0	0	40	0	0	34	0	95			
												*	7339	.9	0.
	75	0	18	0	0	0	40	0	0	35	0	95			
												*	6379	.9	0.
	75	0	19	0	0	0	40	0	0	35	0	95			
												*	5419	.8	0.
810	75	0	20	0	0	0	40	0	0	36	0	95			
												*	4459	.8	0.
	75	0	21	0	0	0	40	0	0	36	0	0			
	*						*			*			4460	5.8	0.
	75	0	22	0	0	0	40	0	0	45	0	0			
	*						*			*			4461	5.7	0.
	75	0	23	0	0	0	40	46	0	45	0	0			
	*							*		*			4476	8.7	8.1
	75	0	24	0	0	0	40	50	0	45	0	0			
	*							*		*			4492	8.7	8.1
815	75	0	25	0	0	0	40	50	0	45	0	0			
	*							*		*			4507	8.7	8.1

VII. COST AND SCHEDULE

A. ADAPTIVE MARS MISSION COSTS

Preliminary cost estimates were made for the four adaptive Mars missions described in this study. The purpose of the estimates was not so much to develop absolute total costs of the missions as to identify the additional costs required to fly adaptive missions compared with fixed sequence missions. To allow this comparison to be made most clearly, the 1979 mission was chosen as the costing baseline. This permitted cross-referencing to existing Viking '79 program estimates, and also avoided the need to mix in space storable propulsion systems which would have distorted the cost comparisons.

The following ground rules were followed in the estimates:

1. 1979 launch opportunity
2. single launch, no spare spacecraft
3. lander and orbiter costs based on Viking '79
   a. maximum inheritance from Viking '75
   b. same subcontractors as Viking '75
   c. same management interfaces as Viking '75
   d. only mandatory spacecraft changes assumed
4. lander and rover costs include 5% target fee
5. orbiter science assumed to be a repeat of the Viking '75 instruments (visual imaging system, Mars atmosphere water detector, and infrared thermal mapper)
6. cost estimates in FY'73 dollars
7. launch vehicle costs not included.

The estimated costs of the four adaptive missions are shown in Table VII-1.

Orbiter costs include the following cost categories related to the development and flight of the orbiter spacecraft.

1. project management and support
2. science support
3. mission analysis and engineering
4. orbiter engineering support
5. hardware subsystems
6. assembly, test and operations
7. ETR operations
8. mission operations

The lander costs shown in the table include the following categories of effort:

1. planning and control
2. mission design and flight operations
3. systems engineering
4. parts materials and processes
5. hardware subsystems
6. assembly test and launch operations
7. mission operations

The factor for lander modifications covers changes to the lander to integrate and land the new payloads.

The NASA support costs cover a number of government furnished equipment items and services.

The costs of adding adaptability to the mission are shown at the bottom of the table. These costs can be added directly to the totals for the non-adaptive missions. The adaptive control system costs cover the data acquisition, processing and

Table VII-1 Cost Estimate - Adaptive Mars Missions (1979)

(FY 73 Dollars in Millions)	Advanced Lander	Adv. Lander Standard Small Rover	Adv. Lander Deluxe Small Rover	Adv. Lander Medium Rover
Orbiter	78	78	78	78
Orbiter Modifications	--	--	--	3
Orbiter Science	10	10	10	10
Lander	113	113	113	113
Lander Modifications	5	5	5	8
Advanced Lander Science	80	80	80	80
Standard Small Rover		6		
Deluxe Small Rover			9	
Medium Rover				98
NASA Support	63	64	65	86
Cost - Non-adaptive Mission	349	356	360	476
Adaptive Control System	8	8	9	9
Adaptive Science Mods	12	12	12	15
Adaptive Operations Software	4	4	5	5
Cost - Adaptive Mission	373	380	386	505

interfacing equipment needed to convert the lander guidance control and sequencing computer into an adaptive controller. The adaptive science modes are changes that would have to be made to the fixed-sequence science instruments to permit them to function with the artificial intelligence systems to form an adaptive payload. The costs for adaptive operations software cover the development of the techniques and tools for programing, modifying and operating the adaptive mission.

As can be seen from these cost estimates the addition of adaptability as described in this study increases the cost of a Mars mission by about 7%.

The science payload assumed for the basic advanced lander is listed in Table VII-2 along with the estimated costs to develop and qualify these instruments. This same payload would be on the lander for each of the four mission configurations.

Table VII-2 Cost Estimate - Advanced Lander Science

(FY 73 Dollars in Millions)

Improved Facsimile Cameras with Magnifier	1
Advanced Biology	25
Wet Chemistry	20
Integrated Geology	15
Soil Water	3
Improved Seismometer	3
Improved Meteorology	2
1-Meter Drill	3
Improved Surface Sampler	2
Science Integration and Support	2
Target Fee (5%)	4
Total	80

B. ADAPTIVE MARS MISSION SCHEDULES

An important conclusion reached in this study is that adaptive missions can incorporate varying degrees of artificial intelligence and levels of sophistication. In other words, adaptability can and probably will be added to planetary missions in steps as we gain more confidence in the approach.

In this study, Mars missions in the 1979 through 1988 time period were considered as candidates for adaptive missions. Depending on the amount of emphasis given to Mars exploration in our space program, progress in developing and flying artificial intelligence for Mars spacecraft may be rapid or more conservative. Figure VII-1 outlines a conservative program of Mars missions showing where the spacecraft concepts described in this study might fit. Other mission configurations are of course feasible for any of these Mars launch opportunities. For example, a mission being given serious consideration at the present time uses minimally modified landers comprised of spare Viking '75 hardware, outfitted with medium rovers capable of sorties out to a kilometer from the landers. The minimal advanced lander as used here may have some new science instruments compared with Viking '75 but would not carry the full complement of experiments listed under the advanced lander configuration in this study.

To illustrate the major program activities and milestones involved in developing an adaptive mission to Mars, the 1981 launch opportunity was chosen as an example. Figure VII-2 is a simplified schedule for an advanced lander with small rover mission incorporating adaptive systems and launched in November or December of 1981. The early activities (1974, 5 and 6) would be supporting research and technology (SRT) work aimed at bringing

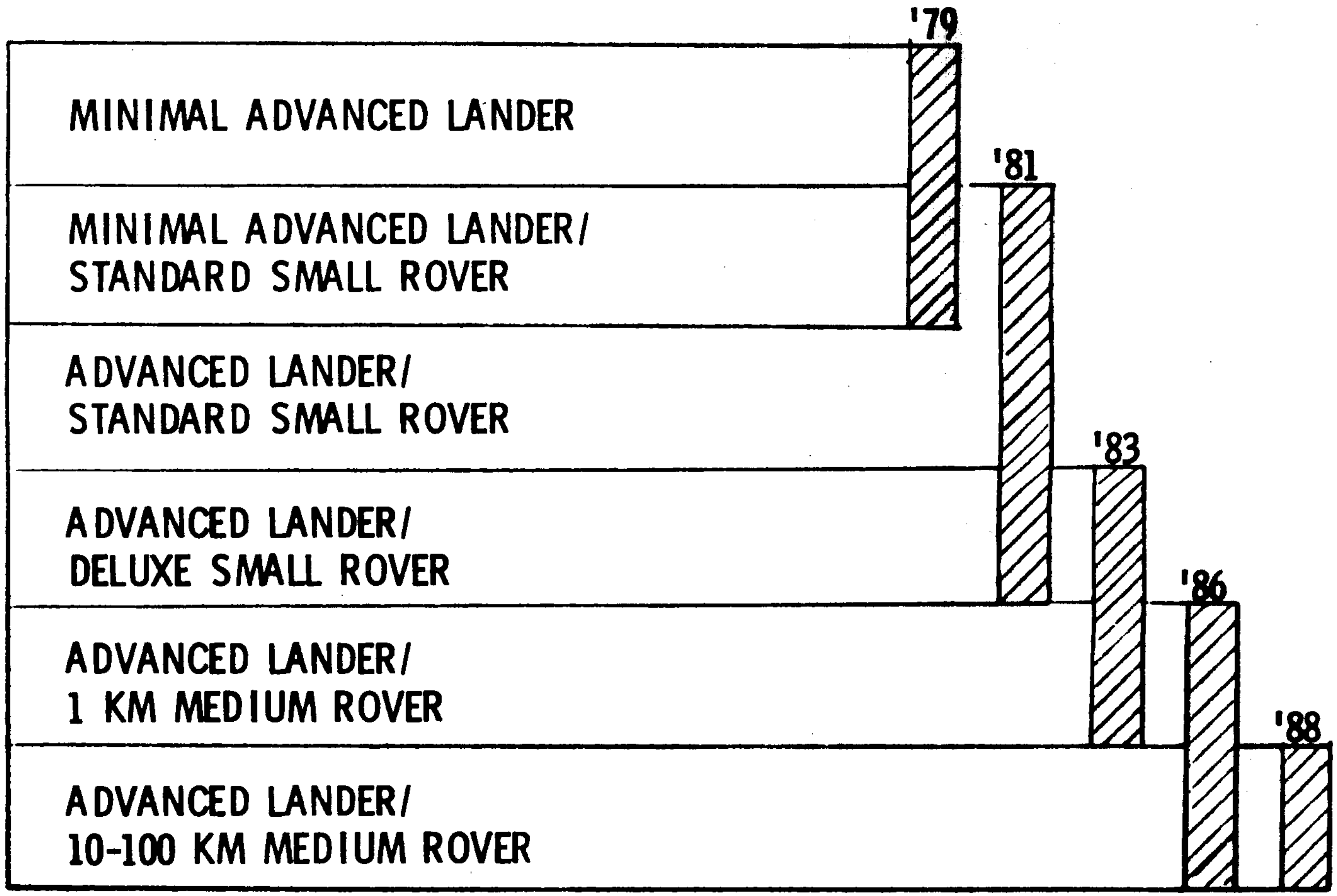


Figure VII-1 Adaptive Systems vs Mars Mission Opportunities

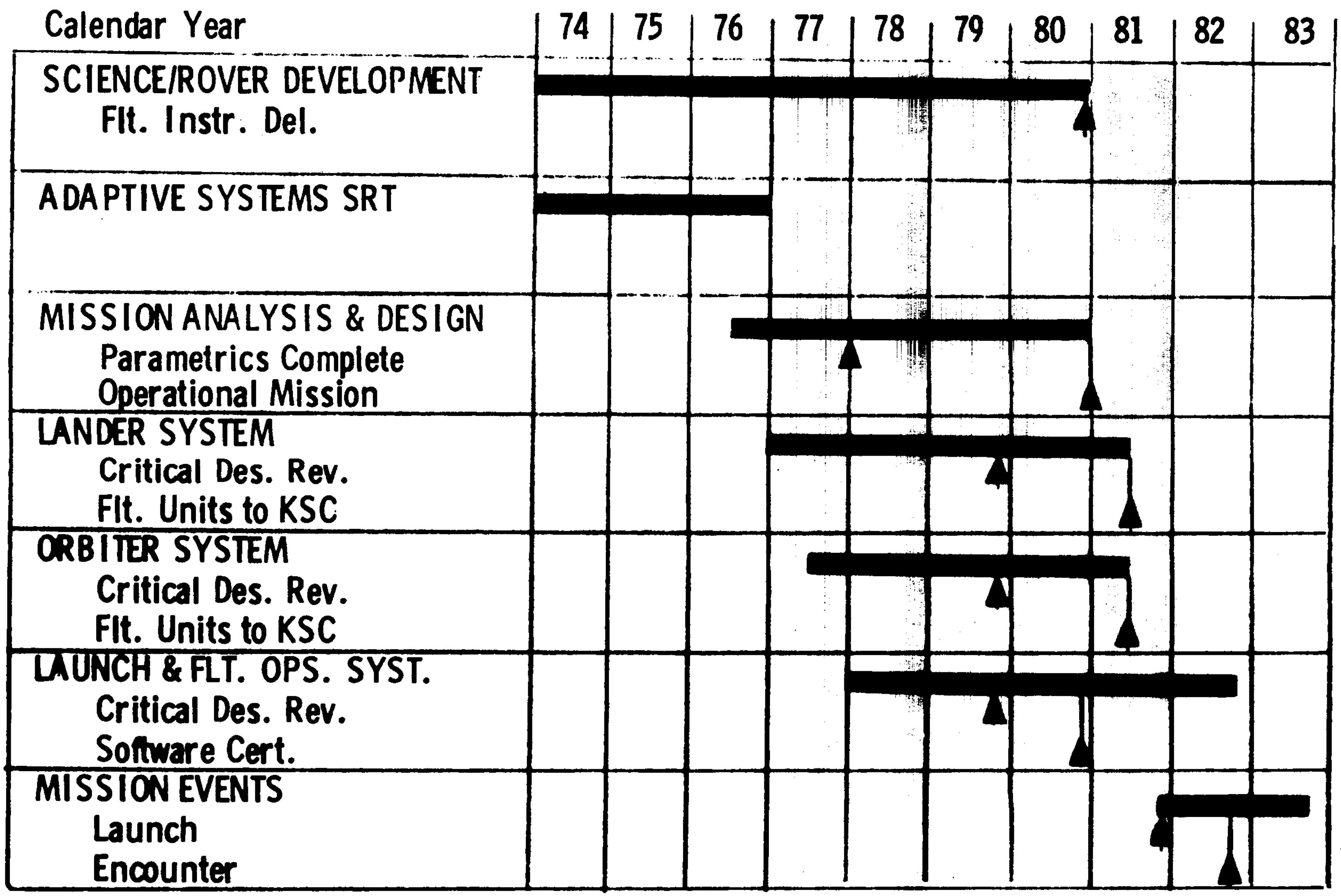


Figure VII-2 1981 Adaptive Mars Mission Schedule the rover, new science and adaptive systems technology development up to the prototype stage prior to full program go-ahead. This schedule assumes that the basic lander and orbiter configurations will be the Viking '75 designs, modified only as necessary to incorporate and deliver the new science, small rover and AI subsystems.

VIII. FUTURE TECHNOLOGY REQUIREMENTS

In the course of the study, items were identified that had large scientific or adaptive potential but needed development before they could be applied to the Mars missions. These are described in more or less detail in preceding chapters and will be listed with a minimum of further discussion.

Scientific instruments include: sample magnifier, x-ray diffractometer, gamma ray spectrometer, neutron activation experiment, active seismometry (mechanical or explosive), flame pyrolysis (for the organic sieve), and rocket or balloon meteorological probes.

Desirable auxiliary equipment for the lander is represented by the landing site selection system and the 1-meter drill.

For the rover concepts to be turned into reality, problems need to be identified and solved in these areas: sampling devices such as scoops, grabbers, drills and sieves; sample manipulation including sorting, protection, and transfer to the lander; cable management for tethered rovers; hazard detection and avoidance; navigational references and dead reckoning systems; miniaturized imaging systems including one that can get a detailed view of the ground; and a control system with a good combination of autonomy and human guidance.

In the general area of adaptive control systems further work needs to be done on designing and testing executive controllers, and a library of useful operating routines needs to be developed. A general-purpose spacecraft computer that can be shared with many other missions would save multiple development costs.

APPENDIX A

EXECUTIVE CONTROLLER

EXECUTIVE CONTROLLER

The executive controller consists of the following program and subroutines:

Main Program - CONTROL
Subroutine - INLOG
Subroutine - BITRUN
Subroutine - LOARG

In the following pages are given a computer listing of this programming and a dictionary of the variables used.

```
      PROGRAM CONTROL(INPUT,OUTPUT,TAPE2=INPUT,TAPE3=OUTPUT)
      DIMENSION J(63),IP(63)
      COMMON/CONTRL/MASTR(63),B,C,TLINE(63),DELAY(63),EXPERT(63)
      COMMON /INTERF/ V(511),DELT,STORAGE
      COMMON/ENGDAT/PWR(63),PRI(63),BPM(63)
      COMMON /PRIOR/PO(63),CO(63),RATE(63),CRATE(63),LIMIT(63),CLIMT(63)
      COMMON /TIMY/T0(63),T1(63),T2(63),T3(63)
      REAL LIMIT
      NAMELIST/INPUT/PO,CO,RATE,CRATE,LIMIT,CLIMT,MASTR,PWR,BPM,
     *DELAY,EXPERT,AL,JJ,TLIMIT,WHMAX,WHMIN,BATMAX,BATCHG,RTG,STORAGE,
     *IRAFG,NIX
      NAMELIST/INFACE/ V
      DATA ASTRIX,BLANK/3H * ,3H    /
      DATA WHMAX,WHMIN,BATMAX,BATCHG,RTG/100.,70.,10.,5.,42./
      DATA IPAFG/0/
      DELT=1.
C
C     INITIALIZE FOR RUN
C
1     READ(2,INPUT)
      IF(NIX.EQ.0)  STOP
      WRITE(3,INPUT)
      READ(2,INFACE)
      WRITE(3,INFACE)
C
C     SET BATTERY WATT-HOURS EQUAL TO MAX
C
C
C     SET AVAILABLE DATA STORAGE TO MAXIMUM
C
      V(473)=STORAGE
      V(474)=WHMAX
```

Figure 1-A PROGRAM LISTING

EXECUTIVE CONTROLLER - MAIN PROGRAM "CONTROL"

```
C
C     BATTERY POWER AVAILABLE A FUNCTION OF WATT-HOURS
C
      V(475)=(V(474)-WHMIN)*BATMAX/(WHMAX-WHMIN)
C
C     SET POWER AVAILABLE TO MAXIMUM
C
      V(476)=RTG
      WRITE(3,100)
C
C     INPUT PRIORITY AND FEASIBILITY EQUATIONS
C
      CALL INLOG
      IF(IRAFG.GT.4) GO TO 9
C
C     SET RANDOM NUMBER GENERATOR ( SEED = TT.
C
      CALL TIME(NT)
      TT=FLOAT(NT)
      TT=ABS(TT)
      D=RANF(TT)
      GO TO 2
9     D=RANF(1.234)
2     DO 3 I=1,JJ
C
C     J REGISTER CONTAINS INDICES OF PRIORITY EQUATIONS
C
      J(I)=I+100
C
C     ALL ROUTINE STATUS INDICATORS SET TO ZERO (OFF)
C
      V(I)=0.
```

Figure 1-B PROGRAM LISTING

EXECUTIVE CONTROLLER - MAIN PROGRAM "CONTROL"

```
C
C     SET INITIAL TURN ON TIME
C
      T1(I)=DELAY(I)+V(480)
C
C     BLANK STATUS PLOT
C
3     TLINE(I)=BLANK
4     ITFG=INT(AMOD(V(480),24.))
      IF(ITFG.EQ.0) WRITE(3,101)
      B=C=0.
C     IRAFG MEANING CODE ****************************************************
C                        *      RANDOM INLOG          *     DON-T READ INLOG     *
C                        * RANDOM DATA *      FIXED DATA        * RANDOM DATA *
C           RANDOM SEED  *      1      *      2       *     3      *     4      *
C           FIXED SEED   *      5      *      6       *     7      *     8      *
C                        ****************************************************
      GO TO (75,75,5,76,75,75,5,76),IRAFG
75    A=RANF(0.)
C
C     ACCEPT RANDOM GROUND COMMANDS
C
      IF(A.GT.AL)   CALL INLOG
      IF(IRAFG.EQ.(2.OR.6)) GO TO 5
76    B=RANF(0.)
      C=RANF(0.)
5     I=J(1)
C
C     EVALUATE PRIORITY EQUATIONS AND SORT IN DESCENDING ORDER
C
      CALL LOARG(I,IX,PRI(I-100))
      IP(I-100)=PRI(I-100)
      DO 8 IK=2,JJ
      K=IK
```

Figure 1-C PROGRAM LISTING

EXECUTIVE CONTROLLER - MAIN PROGRAM "CONTROL"

```
6     IT=J(K-1)
      I=J(K)
      IF(IK.EQ.K)  CALL LOARG(I,IX,PRI(I-100))
      IP(I-100)=PRI(I-100)
      IF(PRI(I-100).LE.PRI(II-100))   8,7
7     JS=J(K-1)
      J(K-1)=J(K)
      J(K)=JS
      K=K-1
      IF(K.GT.1) GO TO 6
8     CONTINUE
      V(477)=V(475)+V(476)
      DO 65 K=1,JJ
      I=J(K)-100
      IF(PRI(I).LT.1.) GO TO 65
C
C     EVALUATE FEASIBILITY EQUATIONS
C
      CALL LOARG(I,IX,X)
      IF(IX.LE.0) GO TO 64
C
C     ROUTINE STATUS INDICATOR SET TO ≠ORDERED ON≠
C
      IF(V(I).EQ.0.)  V(I)=1.
      GO TO (11,12,13,14,15,16,17,18,19,20,21,22),I
11    CALL OPR01
      GO TO 65
12    CALL OPR02
      GO TO 65
13    CALL OPR03
      GO TO 65
14    CALL OPR04
      GO TO 65
```

Figure 1-D PROGRAM LISTING

EXECUTIVE CONTROLLER - MAIN PROGRAM "CONTROL"

```
15    CALL OPRO5
      GO TO 65
16    CALL OPRO6
      GO TO 65
17    CALL OPRO7
      GO TO 65
18    CALL OPRO8
      GO TO 65
19    CALL OPRO9
      GO TO 65
20    CALL OPRO10
      GO TO 65
21    CALL OPRO11
      GO TO 65
22    CALL OPRO12
      GO TO 65
64    V(I)=0.
65    V(477)=V(475)+V(476)
C
C     WRITE PRIORITIES ON PLOT
C
      IOT=INT(AMOD(V(480) ,5.))
      IF(IOT.EQ.0) 66,67
66    WRITE(3,102) V(480),(IP(I),I=1,JJ)
      GO TO 68
67    WRITE(3,103) (IP(I),I=1,JJ)
68    IBAL=IFIX((STOPAGE-V(473))/1000.)
      WRITE(3,104) (TLINE(I),I=1,JJ),IBAL,V(475),V(476)
C
C     SET NEW BATTERY AVAILABLE
C
      V(475)=(V(474)-WHMIN)*BATMAX/(WHMAX-WHMIN)
      IF(V(475).GT.0.9*BATMAX) GO TO 69
      IF(V(476).LT.BATCHG)  GO TO 69
```

Figure 1-E PROGRAM LISTING

EXECUTIVE CONTROLLER _ MAIN PROGRAM "CONTROL"

```
C
C      REDUCE RTG POWER FOR BATTERY CHARGING
C
       V(476)=RTG-BATCHG
C
C      INCREASE BATTERY CHARGE
C
       V(474)=V(474)+DELT*BATCHG/60.
       GO TO 71
C
C      RESET RTG POWER TO MAXIMUM
C
69     V(476)=RTG
71     V(480)=V(480)+DELT
       V(479)=AMOD(V(480)+960.,1440.)
       DO 72 I=1,JJ
72     TLINE(I)=BLANK
       V(22)=1.
       V(23)=1.
       IF(V(480).LE.TLIMIT)  GO TO 4
       GO TO 1
100    FORMAT(1H1)
101    FORMAT(1H1,20X,*ROVER VIEW  ROVER MOTION*,13X,*MEMORY     EXCESS*/
      14X,*TIME*,10X,*TV SPECIAL  ↓  ↓  TV VIEW AHEAD*,9X,*STORED   BAT*,
      23X,*RTG*/
      315X,*CLOUD VIEW  ↓  ↓  ↓  ↓  ROVER PANORAMA*,6X,*KBIT    PWR*,
      43X,*PWR*/
      510X,*CLOUD SEARCH  ↓  ↓  ↓  ↓  ↓  ↓  SEISMOMETER*/
      65X,*HI DATA METEOR  ↓  ↓  ↓  ↓  ↓  ↓  ↓  ↓  HI RATE SEISMO*/
      75X,*METEOROLOGY  ↓  ↓  ↓  ↓  ↓  ↓  ↓  ↓  ↓  ↓  DATA XMISSION*/
      815X,*↓  ↓  ↓  ↓  ↓  ↓  ↓  ↓  ↓  ↓  ↓  ↓*)
102    FORMAT(2X,F6.0,5X,12I3)
103    FORMAT(13X,12I3)
104    FORMAT(14X,12A3,8X,I6,2F6.1)
       END
```

Figure 1-F PROGRAM LISTING

EXECUTIVE CONTROLLER - MAIN PROGRAM "CONTROL"

VARIABLE DICTIONARY - CONTROL

Variable	Common	
A		Random Number A is compared with AL to
AL		Control Limit determine if ground commands are read.
ASTRIX		The symbol (*) plotted for active operating routines.
B	CONTRL	Random number to determine use of number C.
BATCHG		Power required to charge battery.
BATMAX		Maximum power available from battery (fully charged).
BLANK		The symbol ( ) plotted for inactive operating routines.
BPM(63)	ENGDAT	Bits per minute data rate generated by i^{th} routine.
C	CONTRL	Random number to determine magnitude of generated data.
CLIMT(63)	PRIOR	Maximum continuity priority for i^{th} routine.
CO(63)	PRIOR	Continuity priority set when i^{th} routine is activated.
CRATE(63)	PRIOR	Rate at which continuity priority increases with time.
D		Seed for random number generator.
DELAY(63)	CONTRL	Minimum time i^{th} routine must stay off before it is enabled.
DELT	INTERF	Time (minutes) - duration of configuration cycle
EXPERT(63)	CONTRL	Experiment time for i^{th} routine (for normal operation).
I		Index used for operating routines.
IBAL		Thousands of bits of data stored (INTEGER)
IJ		Index of routine have next lowest priority at last cycle.
IK		Temporary operating routine index.
IOT		Integer remainder when mission time is divided by 5.
IP(63)		Priority of i^{th} operating routine (INTEGER)
IRAFG		Random flag.

	Random Command		No Command	
	Events	Fixed	Data	Events
Random Seed	1	2	3	4
Fixed Seed	5	6	7	8

Variable	Common	
ITFG		Integer remainder when mission time is divided by 12 (or number of cycles per page)
IX		Argument of LOARG routine $= -1$ if feasibility ≤ 0; $= +1$ if feasibility > 0
J(63)		Array holding indices of operating routines in order of their priority.

VARIABLE DICTIONARY - COMMON

Variable	Common	
JJ		Number of operating routines.
JS		Temporary storage of J(I) during sorting operation.
K		Temporary index of operating routines.
LIMIT(63)	PRIOR	Maximum priority for i^{th} routine.
MASTR(63)	CONTRL	Flag, controlling routine when operation is interrupted. = -1 cancel; = 0, interrupt; = +1 extend duration.
NI		Argument of supplied by time routine when called.
NIX		Indicator of end of run when zero.
PO(63)	PRIOR	Initial priority assigned to i^{th} routine when enabled.
PRI(63)	ENGDAT	Calculated priority of i^{th} routine.
PWR(63)	ENGDAT	Power consumption of i^{th} routine's hardware.
RATE(63)	PRIOR	Rate at which priority increases with time for i^{th} routine.
RTG		Power output of RTG.
STORAGE	INTERF	Total storage capability (bits).
TLIMIT		Mission time at which run terminates.
TLINE(63)	CONTRL	Array of asterisks and blanks for plotting state of routines.
TT		Random seed for random number generator.
TØ(63)	TIMY	Mission time i^{th} routine turned off.
T1(63)	TIMY	Mission time i^{th} routine is enabled.
T2(63)	TIMY	Mission time i^{th} routine is turned on.
T3(63)	TIMY	Mission time i^{th} routine is signalled off.
V(511)	INTERF	Single value portion of status array.
WHMAX		Maximum watt-hour capacity of battery.
WHMIN		Minimum watt-hour limit of battery (no battery power after this limit)
X		Priority argument of subroutine LOARG.

```
      SUBROUTINE INLOG
      DIMENSION IL(80),VALUE(3),L(322)
      COMMON/CONTRL/MASTR(63),B,C,TLINE(63),DELAY(63),EXPERT(63)
      COMMON /INTERF/ V(511),DELT,STORAGE
      COMMON /PRIOR/PO(63),CO(63),RATE(63),CRATE(63),LIMIT(63),CLIMT(63)
      COMMON /INPOT/CACHE(6,163),NUM(163)
      REAL LIMIT
      ICOUNT=1
1     JTO =0
      READ(2,100) IL
100   FORMAT(80I1)
      NN=16*IL(9)+8*IL(10)+4*IL(11)+2*IL(12)+IL(13)
      IF(IL(1).EQ.0)  RETURN
      IT=IL(80)
C
C     FIND COMMAND ADDRESS, J
C
3     J=32*IL(3)+16*IL(4)+8*IL(5)+4*IL(6)+2*IL(7)+IL(8)+100*IL(2)
      IF(J.EQ.0) 7,4
4     NUM(J)=NN
      I=1
      IF(IT.GT.0) I=14
5     L(I+60*IT)  =IL(I)+1-1
      IF(I.LT.73) 6,16
6     I=I+1
      ICOUNT = ICOUNT +1
      GO TO 5
16    LL=13+NN*10
      ICOUNT=ICOUNT + 1
      IF(ICOUNT.LT.LL)  GO TO 1
      WRITE(3,106) J,(L(I) , I=2,53)
      IF(LL.GT.53)  WRITE(3,108)(L(I),I=54,LL)
106   FORMAT(1X,*J=*,I3,1X,7I1,1X,3I1,4(2X,I1,1X,3I1,1X,3I1,1X,3I1))
108   FORMAT(20X,4(2X,I1,1X,3I1,1X,3I1,1X,3I1))
```

Figure 2-A PROGRAM LISTING

EXECUTIVE CONTROLLER - SUBROUTINE INLOG

```
      DO 2 I=1,LL
2     CALL SETBIT(CACHE(1,J),I,L(I))
      ICOUNT=1
      GO TO 1
C
C     FIND COMMAND INDEX, JTO
C
C     WRITE(3,101)(IL(IK),IK=9,65)
C 101 FORMAT(/1X,3I1,2X,I1,3(1X,3I1),3(2X,I1,1X,8I1,1X,I1,1X,4I1,1X)/)
7     DO 8 M=1,9
      I1=24-M
8     JTO=JTO+IL(I1)*2**M/2
      DO 11 NW=1,3
      J1=J2=0
      I2=10+14*NW
      I3=I2+9
      I5=I2+14
C
C     FIND MANTISSA OF VALUE, J2
C
      DO 9 M=1,8
      I4=I3-M
9     J2=J2+IL(I4)*2**M/2
      IF(ABS(J2).EQ.0) 13,14
13    VALUE(NW)=0.
      GO TO 11
C
C     FIND EXPONENT OF VALUE J1
C
14    DO 10 M=1,4
      I6=I5-M
10    J1=J1+IL(I6)*2**M/2
      IF(J1.GT.14) 12,15
12    WRITE(3,102) JTO,NN
102   FORMAT(/5X,*COMMAND ERROR AT*,I3,*CODE*,I3/)
      GO TO 11
```

Figure 2-B PROGRAM LISTING

EXECUTIVE CONTROLLER - SUBROUTINE INLOG

```
C
C     APPLY SIGN TO EXPONENT J1 AND CALL IT I7
C
15    I7=(2*IL(I3)-1)*J1
      VALUE(NW)=1.
      IF(I7.NE.0)  VALUE(NW)=10.**I7
      VALUE(NW)=VALUE(NW)*FLOAT((2*IL(I2)-1)*J2)
11    CONTINUE
      NAN=NN+1
      IF(JTO.LE.63.AND.NAN.LE.4.OR.NAN.EQ.3)  GO TO 27
      WRITE(3,102) JTO,NN
      GO TO 1
27    GO TO (23,24,25,26),NAN
23    PO(JTO)=VALUE(1)
      RATE(JTO)=VALUE(2)
      LIMIT(JTO)=VALUE(3)
      WRITE(3,103) JTO,PO(JTO),RATE(JTO),LIMIT(JTO)
103   FORMAT(/5X,*COMPONENT *,I3,*   PRIORITY START *,F6.3,*   RATE *,
     1F6.3,*   PRIORITY LIMIT *,F6.3/)
      GO TO 1
24    CO(JTO)=VALUE(1)
      CRATE(JTO)=VALUE(2)
      CLIMT(JTO)=VALUE(3)
      WRITE(3,104) JTO,CO(JTO),CRATE(JTO),CLIMT(JTO)
104   FORMAT(/5X,*COMPONENT*,I3,*   CONTINUITY START *,F6.3,*   RATE *,
     1F6.3,*  CONTINUITY LIMIT *,F6.3/)
      GO TO 1
25    V(JTO)=VALUE(1)
      WRITE(3,105)JTO,V(JTO)
105   FORMAT(/5X,*V-ARRAY CHANGE  V(*,I3,*)= *,F10.5/)
      GO TO 1
26    MASTR(JTO)=INT(VALUE(1))
      WRITE(3,107) JTO,MASTR(JTO)
107   FORMAT(/5X,*MASTER/SLAVE(*,I3,*) = *,I5/)
      GO TO 1
      END
```

Figure 2-C PROGRAM LISTING

EXECUTIVE CONTROLLER - SUBROUTINE INLOG

VARIABLE DICTIONARY - INLOG

Variable	Common	
CACHE(6,163)	INPOT	Equation cache.
CLIMT(63)	PRIOR	Maximum continuity priority for i^{th} routine.
CO(63)	PRIOR	Continuity priority set when i^{th} routine is activated.
CRATE(63)	PRIOR	Rate at which continuity priority increases with time.
DELAY(63)	CONTRL	Minimum time i^{th} routine must stay off before it is enabled.
EXPERT(63)	CONTRL	Experiment time for i^{th} routine (for normal operation)
I		Index of bit on card.
ICOUNT		Index of bit in equation.
IL(80)		Array of bits on input card.
IT		Name of bit in column 80
I1		Index of bits in JTO bits 14 thru 23 command input.
I2		Index of bit giving sign of value's mantissa.
I3		Index of bit giving sign of value's characteristic.
I4		Index of mantissa bits.
I5		Index of bit giving sign of the next value's mantissa.
I6		Index of characteristic bits.
I7		Sign of characteristic $\pm$ 1.
J		Operating routine index - for equation input.
JTO		Command index.
J1		Characteristic of value.
J2		Mantissa of value.
L(322)		Feasibility or priority equation bit array.
LIMIT(63)	PRIOR	Maximum priority for i^{th} routine.
LL		Total number of bits in feasibility or priority equation.
M		Bit index.
MASTR(63)	CONTRL	Flag, controlling routine when operation is interrupted. = -1 cancel; = 0, interrupt; = +1, extend duration.
NAN		NN + 1
NN		Number of blocks in equation or command code.
NUM(163)	INPOT	Number of blocks in i^{th} equation.
NW		Index of word (value in command input).

VARIABLE DICTIONARY - INLOG

Variable	Common	
PO(63)	PRIOR	Initial priority assigned to i^{th} routine when enabled.
RATE(63)	PRIOR	Rate at which priority increases with time i^{th} routine.
TLINE(63)	CONTRL	Array of asterisks and blanks for plotting state of routine.
V(511)	INTERF	Single value portion of status array.
VALUE(3)		Commanded input to status array.

BITRUN

GETBIT	Entry point to bit run--loads 6 octal numbers into 322 bits.
ISUB	Index of bit under consideration.
J	
KSHF	
LMOV	
LNEW	
MASKB	
MASKF	
MASKM	
MASK1	
SETBIT	Entry point to bit run--loads 322 bits into 6 octal numbers.

```
      SUBROUTINE BITRUN(IWRD,IBIT,KWRD)
      DIMENSION IWRD(1)
      DATA MASKF / 07777777777777777776 /
      DATA MASK1 / 0000001 /
C
C        RETRIEVE IBIT STARTING AT IWRD(1) AND PUT THE RESULT IN KWRD
C
      ENTRY GETBIT
      ISUB=(IBIT-1)/60+1
      LMOV=IWRD(ISUB)
      KSHF=ISUB*60-IBIT
      LNEW=LRS(LMOV,KSHF)
      KWRD=LNEW.AND.MASK1
      RETURN
C
C        INSERT KWRD RIGHT BIT INTO IBIT STARTING AT IWRD(1)
C
      ENTRY SETBIT
      ISUB=(IBIT-1)/60+1
      KSHF=ISUB*60-IBIT
      MASKM=LLSF(MASKF,KSHF)
      MASKB=LLS(KWRD,KSHF)
      J=MASKM.AND.IWRD(ISUB)
      IWRD(ISUB)=J.OR.MASKB
      RETURN
      END
```

Figure 3

PROGRAM LISTING

EXECUTIVE CONTROLLER - SUBROUTINE BITRUN

```
      SUBROUTINE LOARG(J,IX,X)
      DIMENSION ARG(20),L(322)
      COMMON /INTERF/ V(511),DELT,STORAGE
      COMMON/ENGDAT/PWR(63),PRI(63),RPM(63)
      COMMON /PRIOR/PO(63),CO(63),RATE(63),CRATE(63),LIMIT(63),CLIMT(63)
      COMMON /INPOT/CACHE(6,163),NUM(163)
      COMMON/CONTRL/MASTR(63),B,C,TLINE(63),DELAY(63),EXPERT(63)
      COMMON /TIMY/T0(63),T1(63),T2(63),T3(63)
      INTEGER OP
      REAL LIMIT
      NA=0
      JHOLD=J
1     NN=NUM(J)
      JCOUNT=0
      LL=13+NN*10
      DO 2  I=1,LL
2     CALL GETBIT(CACHE(1,J),I,L(I))
      DO 44 NB=1,NN
      J1=0
      IF(L(4+10*NB)   .EQ.0) GO TO 26
C
C     FIND STATUS ARRAY INDEX, J1
C
      DO 3 M=1,9
      I1=14+10*NB-M
3     J1=J1+L(I1)*2**M/2
      NA=NA+1
      IF(J1.GT.480) GO TO 4
      ARG(NA)=V(J1)
      GO TO 43
4     I=J
      IF(I.GT.99)  I=I-100
      J1J=J1-480
      IF(J1J.LT.8) GO TO (5,6,7,8,9,10,11),J1J
      J1J=J1-487
      IF(J1J.LT.8) GO TO (12,13,14,15,16,17,43),J1J
5     ARG(NA)=T0(I)
      GO TO 43
```

Figure 4-A PROGRAM LISTING

EXECUTIVE CONTROLLER - SUBROUTINE LOARG

```
6       ARG(NA)=T1(I)
        GO TO 43
7       ARG(NA)=T2(I)
        GO TO 43
8       ARG(NA)=T3(I)
        GO TO 43
9       ARG(NA)=P0(I)
        GO TO 43
10      ARG(NA)=RATE(I)
        GO TO 43
11      ARG(NA)=LIMIT(I)
        GO TO 43
12      ARG(NA)=CO(I)
        GO TO 43
13      ARG(NA)=CRATE(I)
        GO TO 43
14      ARG(NA)=CLIMT(I)
        GO TO 43
15      ARG(NA)=MASTR(I)
        GO TO 43
16      ARG(NA)=BPM(I)
        GO TO 43
17      ARG(NA)=PWR(I)
        GO TO 43
C
C       FIRST DIGIT IN BLOCK INDICATES AN OPERATOR
C
25      I=J
        IF(I.GT.90) I=I-100
        DO 42 ID=1,5,5
        I1=7+10*NB+ID
        I2=I1-1
        I3=I1-2
        I4=I1-3
```

Figure 4-B PROGRAM LISTING

EXECUTIVE CONTROLLER - SUBROUTINE LOARG

```
      OP=8*L(I4)+4*L(I3)+2*L(I2)+L(I1)
      T=ARG(NA)
      IO=OP-6
      IF(OP.EQ.0) GO TO 41
      IF(OP.GT.6) GO TO 27
      IF(OP.EQ.1) ARG(NA-1)=ARG(NA-1)*ARG(NA)
      IF(OP.EQ.2) ARG(NA-1)=ARG(NA-1)+ARG(NA)
      IF(OP.EQ.3) ARG(NA-1)=ARG(NA-1)/ARG(NA)
      IF(OP.EQ.4) ARG(NA-1)=ARG(NA-1)-ARG(NA)
      IF(OP.EQ.5) ARG(NA-1)=AMIN1(ARG(NA),ARG(NA-1))
      IF(OP.EQ.6) ARG(NA-1)=AMAX1(ARG(NA),ARG(NA-1))
      NA=NA-1
      GO TO 41
27    GO TO (28,29,32,35,36,41,41,41,37),IO
28    ARG(NA)=-ARG(NA)
      GO TO 41
29    IF(ARG(NA)-I.EQ.0) 30,31
30    ARG(NA)=1
      GO TO 41
31    ARG(NA)=0.
      GO TO 41
32    IF(ARG(NA-1).LT.ARG(NA)) 33,34
33    ARG(NA-1)=0
      NA=NA-1
      GO TO 41
34    ARG(NA-1)=1
      NA=NA-1
      GO TO 41
35    ARG(NA)=0.
      IF(T.GE.T1(I).AND.(V(I).LT.1.0.OR.V(I).GT.2.0))   ARG(NA)=AMIN1((
     *PO(I)+(T-T1(I))*RATE(I)),LIMIT(I))
      GO TO 41
```

Figure 4-C PROGRAM LISTING

EXECUTIVE CONTROLLER - SUBROUTINE LOARG

```
36     ARG(NA)=0.
       IF(T.GE.T2(I).AND.V(I).GE.2.)      ARG(NA)=AMIN1((CO(I)+(T-T2(I))*
      1CRATE(I)),CLIMT(I))
       GO TO 41
37     J=ARG(NA)
       NA=NA-1
       JCOUNT=1
41     CONTINUE
42     CONTINUE
43     CONTINUE
44     CONTINUE
       IF(J.NE.JHOLD.AND.+COUNT.GE.1)  GO TO 1
       IX=-1
       IF(ARG(1).GT.0.)  IX=1
       K=ARG(1)
       J=JHOLD
       RETURN
       END
```

Figure 4-D PROGRAM LISTING

EXECUTIVE CONTROLLER - SUBROUTINE LOARG

VARIABLE DICTIONARY - LOARG

Variable	Common Block	
ARG(20)		Values in push down stack.
BPM(63)	ENGDAT	Bits per minute-data rate generated by i^{th} routine.
CACHE(6,163)	INPOT	Equation cache.
CLIMT(63)	PRIOR	Maximum continuity priority for i^{th} routine.
CO(63)	PRIOR	Continuity priority set when i^{th} routine is activated.
CRATE(63)	PRIOR	Rate at which continuity priority increases with time.
DELAY(63)	CONTRL	Minimum time i^{th} routine must stay off before it is enabled.
EXPERT(63)	CONTRL	Experiment time for i^{th} routine (for normal operation)
I		Index of bit/also/index of equation.
ID		Index of operator code 315 (either 1 or 6).
IO		Operator code minus six.
I1		Index of bit fourth in operator code/bit index of bits in address block J1.
I2		Index of bit third in operator code.
I3		Index of bit second in operator code
I4		Index of bit first in operator code
JCOUNT		Count of equation extensions = 0 for first 31 blocks.
JHOLD		Temporary storage of equation index while extension is being calculated.
J1		Status array index.
J1J		Index of status array indicators; i.e., J1 - 480 or J1 - 487.
L(322)		Feasibility or priority equation bit array.
LIMIT(63)	PRIOR	Maximum priority for i^{th} routine.
LL		Total number of bits in feasibility or priority equation.
M		Bit index.
MASTR(63)	CONTRL	Flag, controlling routine when operation is interrupted. = -1, cancel; = 0, interrupt; = +1, extend duration.
NA		Number of arguments stored in push down stack.
NB		Index of block in equation.
NN		Total number of blocks.
NUM(163)	INPUT	Total number of equation blocks in i^{th} equation.

VARIABLE DICTIONARY - LOARG

Variable	Common	
OP		Operator code.
PO(63)	PRIOR	Initial priority assigned to i^{th} routine when enabled.
PRI(63)	ENGDAT	Calculated priority of i^{th} routine.
PWR(63)	ENGDAT	Power consumption of i^{th} routine's hardware.
RATE(63)	PRIOR	Rate at which priority increases with time for i^{th} routine.
T		Mission time for calculation of priority from curve.
TLINE(63)	CONTRL	Array of asterisks and blanks for plotting state of routines.
TØ(63)	TIMY	Mission time i^{th} routine is turned off.
T1(63)	TIMY	Mission time i^{th} routine is enabled.
T2(63)	TIMY	Mission time i^{th} routine is turned on.
T3(63)	TIMY	Mission time i^{th} routine is signalled off.
V(511)	INTERF	Single value portion of status array.

APPENDIX B

OPERATING ROUTINE

OPERATING ROUTINE

The following pages contain a computer listing and a variable dictionary of Subroutine OPR02 which is the operating routine used in the system simulation described in Chapter VI and which performs no special functions.

```
      SUBROUTINE OPRO2
      COMMON/ENGDAT/PWR(63),PRI(63),BPM(63)
      COMMON /TIMY/ T0(63),T1(63),T2(63),T3(63)
      COMMON /INTERF/ V(511),DELT,STORAGE
      COMMON/CONTRL/MASTR(63),B,C,TLINE(63),DELAY(63),EXPERT(63)
      DATA ASTRIX,BLANK/3H * ,3H   /
      J=V(2 )
      IF(J.LE.2) 1,2
1     V(476)=V(475)-PWR(2 )
      TLINE(2 )=ASTRIX
      IF(V(476).GE.0.) GO TO 3
      DEF=-V(476)
      V(475)=V(475)-DEF
      V(474)=V(474)-DEF*DELT/60.
      V(476)=0.
      IF(V(475).GE.0.) GO TO 3
      V(475)=V(475)+DEF
      V(474)=V(474)+DEF*DELT/60.
2     V(2 )=0.
      TLINE(2 )=BLANK
      T0(2 )=V(480)
      T1(2 )=T0(2 )+DELAY(2 )
C     RESET BOX
      V(18)=0.
      RETURN
3     V(473)=V(473)-BPM(2 )*DELT
      IF(V(473).GE.0.) GO TO 10
      V(473)=V(473)+BPM(2 )*DELT
      GO TO 2
10    IF(J.GT.1) GO TO 4
      V(2 )=2.
```

Figure 1-A PROGRAM LISTING
MINIMAL OPERATING ROUTINE

```
      T2(2 )=V(480)
      T3(2 )=V(480)+EXPERT(2 )
      T=V(480)
      V(1)=3.
      RETURN
4     IF(V(480).GT.(T+1.001*DELT))  IF(MASTR(2 )) 2,6,5
      GO TO 6
5     T3(2 )=T3(2 )+V(480)-T
6     IF(V(480).GE.T3(2 )) 7,8
7     V(2 )=3.
      RETURN
8     T=V(480)
50    RETURN
      END
```

Figure 1-B PROGRAM LISTING
MINIMAL OPERATING ROUTINE

VARIABLE DICTIONARY - OPRO

Variable	Common	
ASTRIX		The symbol (*) plotted for active operating routines.
BLANK		The symbol ( ) plotted for inactive operating routines.
BPM(1)	ENGDAT	Bits per minute-data rate generated by this routine.
DEF		The amount of power required by this routine not available from RTG.
DELAY(1)	CONTRL	Minimum time this routine must stay off before it is enabled.
DELT	INTERF	Time (minutes) = duration of configuration cycle.
EXPERT(1)	CONTRL	Experiment time for this routine (for normal operation) = V(I) condition of this routine; = 0, off; = 1, ordered on; = 2, on; = 3, ordered off.
MASTR(I)	CONTRL	Flag, controlling routine when operation is interrupted. = -1, cancel; = 0, interrupt; = +1, extend duration.
PRI(I)	ENGDAT	Calculated priority of this routine.
PWR(I)	ENGDAT	Power consumption for this routine's hardware.
T		Mission time this routine was last entered.
TLINE(I)	CONTRL	Symbol indicating state of this routine (*) on, ( ) off.
TØ(I)	TIMY	Mission time this routine was turned off.
T1(I)	TIMY	Mission time this routine was enabled.
T2(I)	TIMY	Mission time this routine was turned on.
T3(I)	TIMY	Mission time this routine will be ordered off.
V(511)	INTERF	Single value portion of status array.

APPENDIX C

SYSTEM SIMULATION PARAMETERS

SYSTEM SIMULATION PARAMETERS

Chapter VI presented a simulation run of the executive controller managing a group of 12 operating routines, each of which is a simulation of an actual routine which would be written to control a science experiment operating in a sepcific mode.

The 12 operating routines are addressed to three lander science instruments: camera, seismometer, and meteorology and a single rover instrument, a camera. The engineering functions of rover motion and data transmission are also simulated. Figure 1 displays this system in block form with some of the principal interactions between the operating routines shown. A more detailed description of these interactions was given in Chapter VI, but the actual interactions are controlled by the feasibility and priority equations.

Feasibility and priority equations are shown in Figure 2 in their binary form, with the feasibility and priority equations interleaved. Table 1 "Feasibility Equations" and Table 2 "Priority Equations" provide translations from the binary numbers and operator codes shown in Figure 1 to a set of octal number addresses and operator symbols, to a set of decimal number addresses and symbols in a normal algebraic notation with brackets and finally to an English translation.

In order that these translations will be easy to understand, several tables are added:

Table 3 - Status Array-Location Assignments

Here the addresses in decimal, octal and binary numbers are given along with the meaning and some of the values assumed.

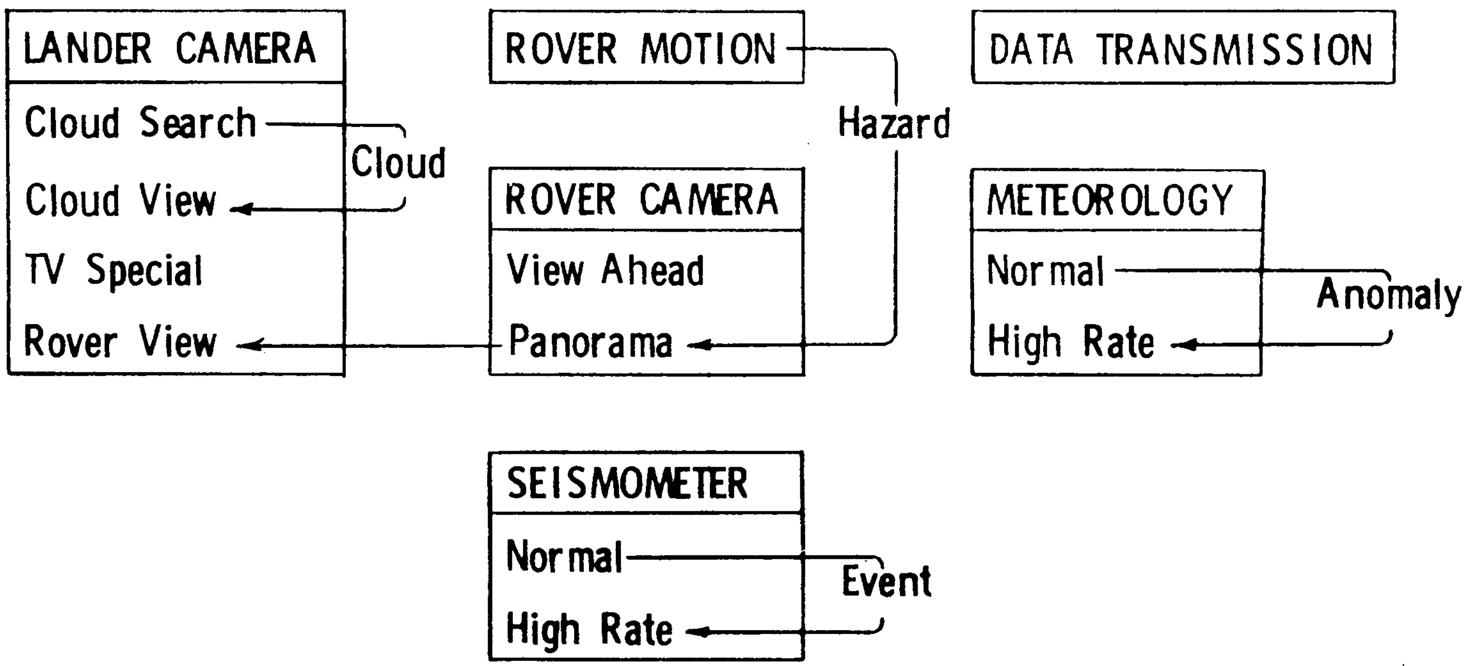


Figure 1 Adaptive System Simulation - Configuration

Table 4 - Status Array - Universal Parameters

The last 17 addresses in the status array designated arrays which have assigned values given for each operating routine. Table 4 lists the values assigned to each routine.

Table 5 - Equation Operator Codes

Although thoroughly described in Chapter V the operator codes are relisted here.

Table 6 - Random Numbers Generated

When the proper value of IRAFG is chosen, various operating routines use the random numbers B & C to produce synthetic data required by feasibility and priority equations. Table 6 gives the limits of B and used to determine which variable is generated and the manner in which C is used.

```
J=   1 0000001 00110  1 111 011 101  1 111 101 101  0 100 100 000  1 111 011 001
                      1 111 101 100  0 100 100 101
J=101 1000001 00110   1 000 000 010  0 011 100 000  1 110 111 111  0 100 100 000
                      1 110 111 110  0 000 100 000
J=   2 0000010 00110  1 111 011 101  1 111 101 101  0 100 100 000  1 111 011 001
                      1 111 101 100  0 100 100 101
J=102 1000010 00011   1 110 111 101  1 000 010 010  0 000 100 000  0 000 000 000
J=   3 0000011 01100  1 111 011 101  1 111 101 101  0 100 100 000  1 111 011 001
                      1 111 101 100  0 100 100 101  1 000 011 111  0 010 100 000
                      1 000 111 001  0 010 100 000  1 000 010 110  0 010 100 000
J=103 1000011 01011   1 111 100 000  0 101 000 000  1 111 100 000  0 101 100 110
                      1 111 000 000  1 111 011 111  0 100 100 001  1 000 001 101
                      0 100 000 000  1 111 000 001  0 000 100 110
J=   4 0000100 01100  1 111 011 101  1 111 101 101  0 100 100 000  1 111 011 001
                      1 111 101 100  0 100 100 101  1 000 011 111  0 010 100 000
                      1 000 111 001  0 010 100 000  1 000 010 110  0 010 100 000
J=104 1000100 01101   1 111 100 000  0 101 000 000  1 111 100 000  0 101 100 110
                      1 000 010 100  0 000 100 000  1 111 000 000  1 111 011 111
                      0 100 100 001  1 000 001 101  0 100 000 000  1 111 000 001
                      0 000 100 110
J=   5 0000101 01100  1 111 011 101  1 111 101 101  0 100 100 000  1 111 011 001
                      1 111 101 100  0 100 100 101  1 000 011 111  0 010 100 000
                      1 000 111 001  0 010 100 000  1 000 010 110  0 010 100 000
J=105 1000101 01010   1 111 100 000  0 101 000 000  1 111 100 000  0 101 100 110
                      1 111 100 000  1 000 011 001  0 100 100 001  1 000 011 010
                      1 111 100 000  0 100 100 001
J=   6 0000110 01100  1 111 011 101  1 111 101 101  0 100 100 000  1 111 011 001
                      1 111 101 100  0 100 100 101  1 000 011 111  0 010 100 000
                      1 000 111 001  0 010 100 000  1 000 010 110  0 010 100 000
J=106 1000110 01010   1 111 100 000  0 101 000 000  1 111 100 000  0 101 100 110
                      1 000 101 001  1 000 101 010  0 100 100 001  1 111 101 000
                      1 000 101 111  0 000 100 110
J=   7 0000111 10010  1 111 011 101  1 111 101 101  0 100 100 000  1 111 011 001
                      1 111 101 100  0 100 100 101  1 000 110 111  0 010 100 000
                      1 000 111 001  0 010 100 000  1 000 010 111  0 000 100 000
                      1 000 110 000  0 000 100 000  1 000 010 110  0 011 100 000
                      1 110 111 111  0 100 100 001
```

Figure 2-A SYSTEM SIMULATION - EQUATION CACHE INPUT

```
J=107 1000111 01001  1 111 100 000  0 101 000 000  1 111 100 000  0 101 100 110
                     1 000 101 110  1 000 110 010  1 111 000 011  0 100 100 101
                     0 000 100 000
J=  8 0001000 01010  1 111 011 101  1 111 101 101  0 100 100 000  1 111 011 001
                     1 111 101 100  0 100 100 101  1 000 011 111  0 010 100 000
                     1 000 010 111  0 010 100 000
J=108 1001000 10100  1 000 110 100  1 000 101 011  0 100 100 000  1 111 100 101
                     0 000 100 000  1 111 000 011  1 000 001 000  0 100 100 001
                     1 111 101 000  1 000 001 000  1 111 000 100  0 100 100 001
                     0 011 000 000  1 111 000 000  1 111 011 111  0 100 100 001
                     1 000 001 101  0 100 000 000  1 111 010 001  0 000 100 110
J=  9 0001001 01010  1 111 011 101  1 111 101 101  0 100 100 000  1 111 011 001
                     1 111 101 100  0 100 100 101  1 000 011 111  0 010 100 000
                     1 000 010 111  0 010 100 000
J=109 1001001 11001  1 000 101 001  1 000 101 011  0 100 100 000  1 111 100 101
                     0 000 100 000  1 111 000 011  1 000 001 001  0 100 100 001
                     1 000 001 001  1 111 000 100  0 100 100 000  1 111 101 000
                     0 000 100 110  1 111 000 000  1 111 011 111  0 100 100 001
                     1 000 001 101  0 100 000 000  1 111 000 001  0 000 100 110
                     1 111 000 011  1 000 110 000  0 010 000 000  1 111 101 000
                     0 000 100 110
J= 10 0001010 01000  1 111 011 101  1 111 101 101  0 100 100 000  1 111 011 001
                     1 111 101 100  0 100 100 101  1 000 111 001  0 010 100 000
J=110 1001010 01000  1 111 100 000  0 101 000 000  1 111 100 000  0 101 100 110
                     1 000 001 101  0 100 000 000  1 111 000 001  0 000 100 110
J= 11 0001011 00110  1 111 011 101  1 111 101 101  0 100 100 000  1 111 011 001
                     1 111 101 100  0 100 100 101
J=111 1001011 00111  1 111 000 010  1 000 111 010  0 000 100 000  1 111 000 001
                     1 000 001 101  0 100 000 001  0 011 000 000
J= 12 0001100 00011  1 111 011 101  1 111 101 101  0 100 100 000  0 000 000 000
J=112 1001100 01110  1 111 100 000  0 101 000 000  1 111 100 000  0 101 100 110
                     1 000 111 101  1 000 111 110  0 001 000 000  1 111 100 000
                     0 100 100 000  1 111 100 000  1 000 111 101  1 000 111 110
                     0 010 001 001  0 010 100 001
```

Figure 2-B SYSTEM SIMULATION - EQUATION CACHE INPUT

Table 1-A

FEASIBILITY EQUATIONS

1 - METEOROLOGY

735 755 if 731 754 if Λ

V(477) V(493) if V(473) V(492) if Λ

TPWR PWR if Storage BPM if Λ

(TPWR if PWR) Λ (STORAGE if BPM)

OK IF: power and memory are available

2 - HIGH DATA METEOROLOGY

735 755 if 731 754 if Λ

V(477) V(493) if V(473) V(492) if Λ

TPOR PWR if STORAGE BPM if Λ

(TPWR if PWR) Λ (STORAGE if BPM)

OK IF: power and memory are available

3 - CLOUD SEARCH

735 755 if 731 754 if Λ 37 Λ 71 Λ 26 Λ

V(477) V(493) if V(473) V(492) if Λ V(31) Λ V(57) Λ V(22) Λ

(V(477) if V(493)) Λ(V(473) if V(492)) ΛV(31) Λ V(47) Λ V(22)

OK IF: power and memory are available and wind is not over placard and hi rate seismometer is off and no other lander TV is on

4 - CLOUD VIEW

735 755 if 731 754 if Λ 37 Λ 71 Λ 26 Λ

V(477) V(493) if V(473) V(492) if Λ V(31) Λ V(57) Λ V(22) Λ

(V(477) if V(493)) Λ (V(473) if V(492)) Λ V(31) Λ V(57) Λ V(22)

OK IF: power and memory are available and wind is not over placard and hi rate seismometer is off and no other lander TV is on

Table 1-A

FEASIBILITY EQUATIONS

5 - TV SPECIAL

735 755 if 731 754 if ∧ 37 ∧ 71 ∧ 26 ∧

V(477) V(493) if V(473) V(492) if ∧ V(31) ∧ V(57) ∧ V(22) ∧

(V(477) if V(493)) ∧ (V(473) if V(492)) ∧ V(31) ∧ V(57) ∧ V(22)

OK IF: power and memory are available and wind is not over placard and hi rate seismometer is off and no other lander TV is on

6 - ROVER VIEW

735 755 if 731 754 if ∧ 37 ∧ 71 ∧ 26 ∧

V(477) V(493) if V(473) V(492) if ∧ V(31) ∧ V(57) ∧ V(22) ∧

(V(477) if V(493)) ∧ (V(473) if V(492)) ∧ V(31) ∧ V(57) ∧ V(22)

OK IF: power and memory are available and wind is not over placard and hi rate seismometer is off and no other lander TV is on

7 - ROVER MOTION

735 755 if 731 754 if ∧ 63 ∧ 71 ∧ 27 *
60 if * - 677 if *

V(477) V(493) if V(473) V(492)if ∧ V(51) ∧ V(57) ∧ V(23)*
V(48) * $\overline{V(6)}$ V(447)if*

(V(477)if V(493))∧(V(473)if V(492))∧ V(51)∧ V(57)* V(23)*V(48)*
$\overline{V(6)}$ if zero

OK IF: power and memory are available and wind is below placard and hi rate seismometer is off and no hazard has been detected and ROVER VIEW is off

8 - ROVER TV - VIEW AHEAD

735 755 if 731 754 if ∧ 37 ∧ 27 ∧

V(477) V(493) if V(473) V(492) if ∧ V(31) ∧ V(23) ∧

(V(477) if V(493)) ∧ (V(473) if V(492)) ∧ V(31) ∧ V(23)

OK IF: power and memory are available and wind is below placard and rover TV is not already on

Table 1-B

FEASIBILITY EQUATIONS

9 - ROVER TV - PANORAMA

735 755 if 731 754 if ∧ 37 ∧ 27 ∧

V(477) V(493) if V(473) V(492) if ∧ V(31) ∧ V(23) ∧

(V(477) if V(493)) ∧ (V(473) if V(492)) ∧ V(31) ∧ V(23)

OK IF: power and memory are available and wind is below placard and rover TV is not already on

10 - SEISMOMETER

735 755 if 731 754 if ∧ 71 ∧

V(477) V(493) if V(473) V(492) if ∧V(57) ∧

(V(477) if V(493)) ∧ (V(473) if V(492)) ∧ V(57)

OK IF: power and memory are available and hi rate seismometer is off

11 - HIGH RATE SEISMOMETER

735 755 if 731 754 if ∧

V(477) V(493) if V(473) V(492) if ∧

(V(477) if V(493)) ∧ (V(473) if V(492))

OK IF: power and memory are available

12 - DATA TRANSMISSION

735 755 if

V(477) V(493) if

V(477) if V(493)

OK IF: power is available

Table 2-A

PRIORITY EQUATIONS

101 - METEOROLOGY

2 not 677 if 676 *

V(2) V(447) if V(446) *

(V(2) if zero) * 75 V(446) = a constant 75

PRIORITY is 75 except when hi data meteorology is on when it is zero

102 - HI RATE METEOROLOGY

675 22 *

V(445) V(18) * = 80 * V(18)

PRIORITY is 80 when a weather anomaly has been observed otherwise zero

103 - CLOUD SEARCH

740 p 740 c U 700 737 if * 15 = 701 * U

V(480) p V(480) c U V(448) V(479) if * V(13) = V(449) * U

(V(480) P U V(480) c) * (V(448) if V(479)) U (V(13)=* V(449))

Priority Curve * (600 if daytime) U (V(13)=* 99)

PRIORITY is the priority curve if it is daylight or 90 if commanded on

104 - CLOUD VIEW

740 p 740 c U 700 737 if * 15 = 701 * U

V(480) p V(480) c U V(448) V(479) if * V(13) = V(449) * U

[(V(480) p U V(480) c) * (V(448) if V(479))] U (V(13)=* V(449))

Priority Curve * (600 if daytime) U (V(13)=* 99)

PRIORITY is the priority curve if it is daylight or 99 if commanded on

Table 2-A

PRIORITY EQUATIONS

105 - TV SPECIAL

740 p 740 c U 740 31 if * 32 740 if *

V(480) p V(480) c U V(480) V(25) if * V(26) V(480) if *

(V(480) p U V(480) c) * (V(480) if V(25)) * (V(26) if V(480))

Priority Curve * (T if T_1) * (T_2 if T) if T = time
T_1 = V(25) T_2 = V(26)

PRIORITY is the priority curve if $T_1 \leq T \leq T_2$

Table 2-B

PRIORITY EQUATIONS

106 - ROVER VIEW

740 p 740 c U 51 52 if * 750 57 * U

V(480) p V(480) c U V(41) V(42) if * V(488) V(47) * U

[(V(480) p U V(480) c) * (V(41) if V(42))] U (V(488) * V(47))

Priority Curve * Distance $\geq$ limit U CO when rover panorama complete

PRIORITY is the priority curve providing that the rover has traveled further than the established limit or equal to the maximum continuity limit when the rover camera completes a panorama

107 - ROVER MOTION

740 p 740 c U 56 *

V(480) p V(480) c U V(46) *

(V(480) p U V(480) c) * V(46)

PRIORITY is the priority curve providing that no new soil is detected

Table 2-B

PRIORITY EQUATIONS

108 - ROVER TV - VIEW AHEAD

```
64     53     if 745     * 703    10     if * 750     10     704
              if * U 700  737    if * 15    = 701     * U
```

```
V(42) V(43) if V(485) * V(451) V(8) if * V(488) V(8) V(452)
            if U V(448) V(479) if * V(13) = V(449) * U
```

```
[((V(42) if V(43)) * V(485) * (V(451) if V(8)) U (V(488) * (V(8)
            if V(452))] * (V(448) if V(479)) U (V(13) = * V(449))
```

PRIORITY is PO(8) if distance travelled is greater than nominal distance between TV views ahead and the routine is off OR CO(8) if the routine is on providing in either case that it is daylight OR the priority is 99 when the routine is commanded on

109 - ROVER TV - PANORAMA

```
51     52     if 745     * 703     11     if * 11     704     if 750
       * U 700   737    if * 15    + 701    * U 703   60   = 750      * U
```

```
V(41) V(42) if V(485) * V(451) V(9) if * V(9) V(452) if V(488)
      * U V(448) V(479) if * V(13) = V(449) * U V(451) V(488) * U
```

```
[((V(41) if V(42)) * V(485) * (V(451) if V(9))) U ((V(9) if V(452))
      * V(488))]* (V(448) if V(479)) U (V(13) = * V(449)) U (V(451)
      = V(48) * V(488))
```

PRIORITY is PO(9) if the distance travelled is greater than the nominal distance between panoramas and the routine is off OR CO(9) if the routine is on providing in either case that it is daylight OR the priority is 99 if commanded on OR it is CO(9) if a rover hazard has been detected

Table 2-C

PRIORITY EQUATIONS

110 - SEISMOMETER

```
740     p 740     c U 15     = 701     * U
```

```
V(480) p V(480) c U V(13) = V(449) * U
```

```
(V(480) p U V(480) c) U (V(13) = * V(449))
```

Priority Curve U commanded on

PRIORITY is priority curve or 99 if commanded on

Table 2-C

PRIORITY EQUATIONS

111 - HIGH RATE SEISMOMETER

702 72 * 701 15 = * U

V(450) V(58) * V(449) V(13) = * U

(V(450) * V(58)) U (V(449) * V(13) =)

(90 * $\genfrac{}{}{0pt}{}{\text{limit}}{\text{exceeded}}$) U (99 if commanded)

PRIORITY is 90 when seismic limit is exceeded or 99 if commanded on

112 - DATA TRANSMISSION

740 p 740 c U 75 76 + 740 if 740 75 76

- if Λ *

V(480) p V(480)c U V(61) V(62) + V(480) if V(480) V(61) V(62)

- if Λ *

(V(480) p U V(480) c) * ((V(61) + V(62)) if V(480) Λ (V(480) if (v(61) - V(62)))

Priority Curve T_p + delta time T_p - delta

PRIORITY is priority curve when mission time is within delta minutes of periapsis of the orbiter

Table 3-A

STATUS ARRAY LOCATION ASSIGNMENTS

Index	Octal	Binary	Parameter Meaning	Initial Value	Special Value
1	001	000 000 001	Meteorology Status	0	
2	002	000 000 010	High Data Meteorology Status	0	
3	003	000 000 011	Cloud Search Status	0	
4	004	000 000 100	Cloud View Status	0	
5	005	000 000 101	TV Special Status	0	
6	006	000 000 110	Rover View Status	0	
7	007	000 000 111	Rover Motion Status	0	=1 if ordered on
8	010	000 001 000	TV View Ahead Status	0	=2 if on
9	011	000 001 001	Rover Panorama Status	0	=3 if ordered off
10	012	000 001 010	Seismometer Status	0	
11	013	000 001 011	High Rate Seismometer Status	0	
12	014	000 001 100	Data Transmission Status	0	
13	015	000 001 101	Command Index	0	
15	017	000 001 111	Wind Velocity m/sec	0	Random No.
16	020	000 010 000	Maximum Wind for TV	3	
17	021	000 010 001	Maximum Wind for Rover	5	
18	022	000 010 010	Weather Anomaly	0	=1 if present
20	024	000 010 100	Cloud Event	0	=1 if present
22	026	000 010 110	Lander TV Condition	1	=0 if any on
23	027	000 010 111	Rover TV Condition	1	=0 if any on
25	031	000 011 001	Earliest Time For TV	0	
26	032	000 011 010	Latest Time Special	0	
31	037	000 011 111	TV Wind Placard	1	=0 if wind too high
38	046	000 100 110	Rover Velocity	0.5	
41	051	000 101 001	Distance after Panorama	0	
42	052	000 101 010	Max Distance after Panorama	10	
43	053	000 101 011	Max Distance after TV View	2.5	
44	054	000 101 100	Rover Tilt (degrees)	0	Random No.

Table 3-B

STATUS ARRAY LOCATION ASSIGNMENTS

Index	Octal	Binary	Parameter	Intial Value	Special Value
45	055	000 101 101	Maximum Rover Tilt	15	
46	056	000 101 110	XRFS Result on Soil	1	=0 if new type
47	057	000 101 111	Rover Pan Completed	0	=1 if done
48	060	000 110 000	Hazard Detector Status	1	=0 if detected
50	062	000 110 010	Commanded Rover Travel (m)	15	
51	063	000 110 011	Rover Wind Placard	1	=0 if wind too high
52	064	000 110 100	Distance after View Ahead	0	
53	065	000 110 101	Tether Tension	0	Random No.
54	066	000 110 110	Maximum Tether Tension	0	
55	067	000 110 111	Seismic Level Measured	0	
56	070	000 111 000	Established Event Level	10	Function of wind
57	071	000 111 001	High Seismometer Status	1	=0 if on
58	072	000 111 010	Seismic Event Level Status	0	=1 if exceeded
59	073	000 111 011	Seismic Wind Sensitivity	2	
61	075	000 111 101	Time of Orbiter Periapsis	800	
62	076	000 111 110	± Transmission Time (min)	10	
63	077	000 111 111	Orbiter Period Minutes	1477	
445	675	110 111 101	Priority of Hi Meteor	80	
446	676	110 111 110	Priority of Meteorology	75	
447	677	110 111 111	Zero	0	
448	700	111 000 000	Total Minutes of Daylight	600	
449	701	111 000 001	Priority of Ground Commands	99	
450	702	111 000 010	Priority of High Seismometry	90	
451	703	111 000 011	Unity	1	
452	704	111 000 100	Two	2	

Table 3-C

STATUS ARRAY LOCATION ASSIGNMENTS

Index	Octal	Binary	Parameter Meaning	Initial Value	Special Value
472	730	111 011 000	Transmission Rate BPM	960,000	
473	731	111 011 001	Memory Storage Available	30,000,000	
474	732	111 011 010	Battery Watt-hours Avail	100	
475	733	111 011 011	Battery Power Available	10	
476	734	111 011 100	RTG Power Available	42	
477	735	111 011 101	Total Power Available	52	
479	737	111 011 111	Minutes after 8AM	240	
480	740	111 100 000	Mission Time (minutes)	720	
481	741	111 100 001	Mission Time i^{th} routine is turned off		
482	742	111 100 010	Mission time 1^{th} rottine is enabled		
483	743	111 100 011	Mission time i^{th} routine is turned on		
484	744	111 100 100	Mission time i^{th} routine is ordered off		
485	745	111 100 101	Initial Priority of i^{th} routine		
486	746	111 100 110	Priority increase rate i^{th} routine		
487	747	111 100 111	Priority limit i^{th} routine		
488	750	111 101 000	Initial continuity priority i^{th} routine		
489	751	111 101 001	Continuity priority rate i^{th} routine		
490	752	111 101 010	Continuity priority limit i^{th} routine		
491	753	111 101 011	Interrupt flag i^{th} routine		
492	754	111 101 100	Data generation rate (BPM) i^{th} routine		
493	755	111 101 101	Power consuption i^{th} routine		

Table 4

STATUS ARRAY - UNIVERSAL PARAMETERS

	DELAY	PO	RATE	LIMIT	EXPERT	CO	POWER	BPM	MASTR
1	0	75	0	75	50	75	5	10	-1
2	2	80	0	80	5	80	5	100	0
3	10	0	1	55	6	55	18.9	15360	0
4	10	75	1	85	5	85	18.9	960000	1
5	5	20	0.5	38	30	65	18.9	960000	1
6	10	30	0	30	5	70	18.9	960000	-1
7	2	10	1	40	5	40	30	500	-1
8	2	46	0	46	10	50	18.9	15360	1
9	10	43	0	43	15	60	18.9	15360	1
10	0	20	0.5	45	14	45	10	97	0
11	2	90	0	90	2	90	12	2160	1
12	30	95	0	95	21	95	50		-1

Table 5

EQUATION OPERATOR CODES

TYPE	OPERATORS	SYMBOL	CODE	REMARKS
Arithmetic	Multiply	A X B	0001	
	Addition	A + B	0010	
	Division	A $\div$ B	0011	
	Subtraction	A - B	0100	
Boolean	AND	A $\cap$ B	0101	The lesser of A and B
	OR	A U B	0110	The greater of A and B
	NOT	$\bar{A}$	0111	Minus A
Special	Equal	A=	1000	=1 if A=J or =-1 if A$\neq$J where J is the index of routine
	If	A If B	1001	=1 if A $\geq$ B or =0 if A $<$ B
	P	A p	1010	Evaluates priority equation at A
	C	A c	1011	Evaluates continuity equation at A
	Set	J = A	1111	Sets the index of the equation equal to previously stored value A. In this way equation A is treated as a continuation of the last equation.

Table 6.

RANDOM NUMBERS GENERATED

Operating Routine	B Lower	B Upper	Status Array Address	Variable Description	Function Using C
METEOROLOGY	0.045	0.08	V(15)	Wind Velocity	$V(15) = 10\ C^2$
	0.17	0.205	V(18)	Weather Anomaly = 1	V(18) = 1
CLOUD SEARCH	0.295	0.36	V(20)	Cloud Event = 1	V(20) = 1
ROVER MOTION	0.42	0.455	V(44)	Rover Tilt	V(44) = 4.5/C also V(48) = 0
	0.545	0.58	V(53)	Tether Tension	$V(53) = 0.3/C^2$
	0.67	0.705	V(48)	Obstruction Present = 0	V(48) = 0
	0.795	0.83	V(46)	New Soil Found = 0	V(46) = 0
SEISMOMETER	0.92	0.955	V(55)	Seismic Level Measured	$V(55) = 20\ C^2$

APPENDIX D

SAMPLE SCREENING

SAMPLE SCREENING

This appendix describes a routine which characterizes a set of measurements for example a spectrum, as a vector in n-space. If the n samples are judiciously chosen, the magnitude of the difference between two such vectors determines whether the two spectra they represent are from the same class or not. The magnitude of the difference (or separation) is the definition of the class size.

In the section on computer sizing V-D, it was stated that sample screening (Routine A) required 1390 words of memory. The routine described in this appendix requires only 975 words since n is four instead of ten and only one vector is considered instead of two separate ones.

Figure 1 which is a flow diagram of the routine, shows that the first step is to input the separation distance and to set components of the vectors, Z, to zero. In some cases it might be useful to be able to set the components to some a priori class but in the case for which this routine was written, the x-ray fluorescence spectrometer, it was felt that it would be dangerous to assume elemental composition of the rocks of Mars based on knowledge of those of the Earth. On the other hand, the spectra from a mass spectrometer might be more predictable.

The next step is to add groups of the 64 output channels to form the components of the vector. For example, the first component is the addition of the counts in channels 45 through 50; the second component is the sum of the counts in channels 32 through 35; the third component is the sum of the counts in channels 25 through 28 and the fourth component is the sum of channels 17 through 21.

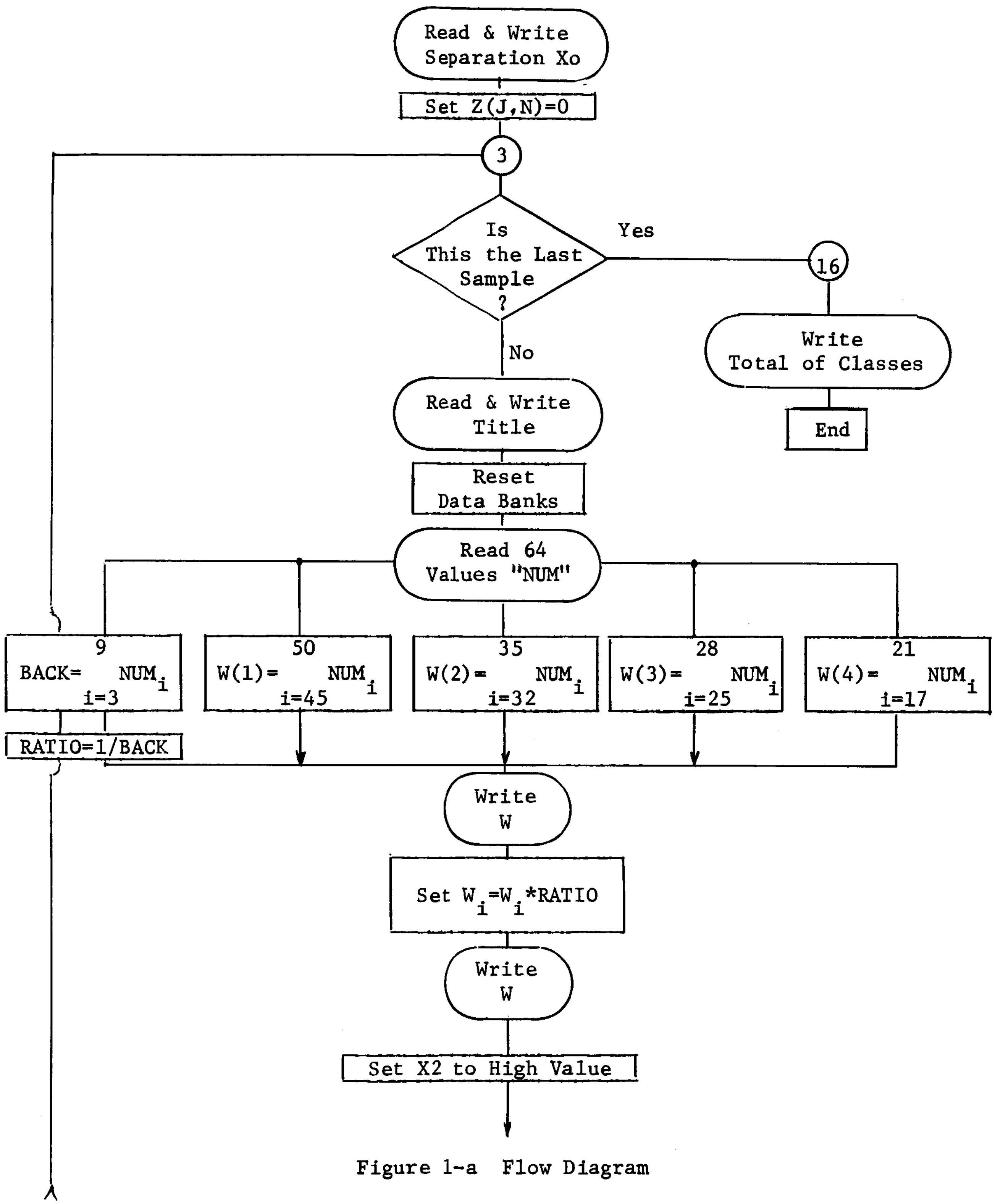


Figure 1-a Flow Diagram

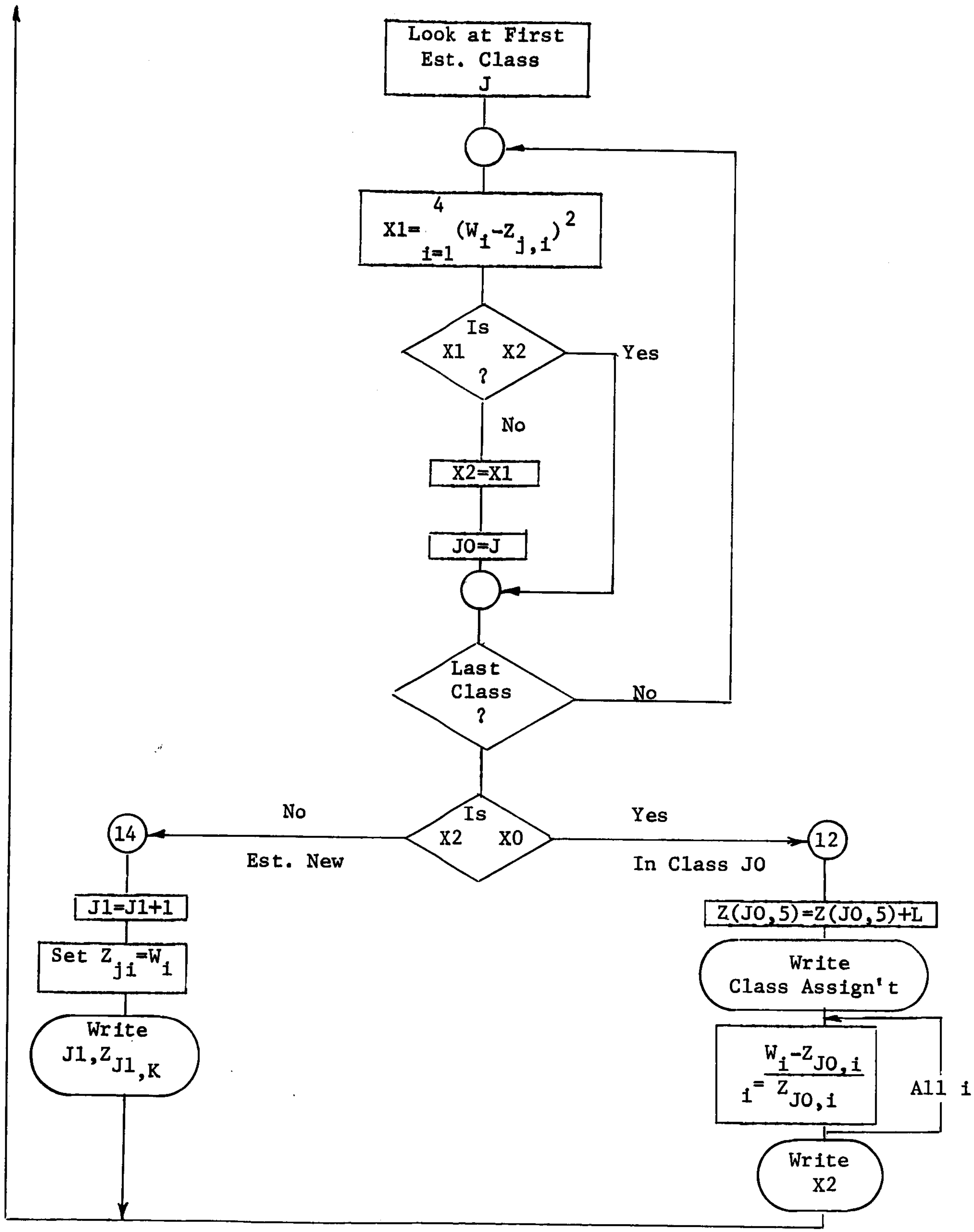


Figure 1-b Flow Diagram

Some normalization process must be used to place the data from various runs on the same basis, here the number of counts for any channel is not only a function of the elemental composition of the sample, but also the time over which the counts were accumulated and the distance between the sample and the x-ray source and proportional counter. Channels 3 through 9 are essentially a backscatter from the x-ray source and are therefore, in proportion to the time and distances mentioned. The required normalization is the division of the component counts by this background count in order to eliminate the time and distance uncertainties.

The separation distance, X1, which is the sum of the squares of the differences between the components of the measured sample and the components of an established class is determined. A value for X1 is determined for each previously established class and a determination is made of the index, J0, of the class which is closest to the sample being screened. The separation, X2, of the closest class is then compared to the input separation distance X0 to determine whether the sample in question belongs to the closest class J0 or whether a new class J1 should be established. When this determination is made, the components of the new class or of the old class are printed out. In the latter case the fractional difference is also printed out.

In order to provide further understanding of this routine, a program listing, Figure 2, and a dictionary of variables, Table 1 are provided.

In addition, Figure 3 shows the start of a printout from this routine using actual XRFS data. The first line in each sample is the title which in this case is the date February 10, 1972 and a serial number 01 through 05. This title line is then

```
      PROGRAM SORT1(INPUT,OUTPUT,TAPE2=INPUT,TAPE3=OUTPUT)
      DIMENSION Z(40,5),DELT(4),TITLE(4),NUM(64),W(4)
      READ(2,95) X0
      WRITE(3,94) X0
      J1=0
      DO 2 J=1,40
      DO 2 K=1,5
2     Z(J,K)=0.
3     READ(2,99) IL
      IF(IL.EQ.0) GO TO 16
      READ(2,98) TITLE
      WRITE(3,97) TITLE
      BACK =0.
      DO 1 I=1,4
1     W(I)=0.
      READ(2,96) NUM
      DO 4 I=3,9
4     BACK=NUM(I)+BACK
      RATIO=1./BACK
      DO 5 I=45,50
5     W(1)=W(1)+NUM(I)
      DO 6 I=32,35
6     W(2)=W(2)+NUM(I)
      DO 7 I=25,28
7     W(3)=W(3)+NUM(I)
      DO 8 I=17,21
8     W(4)=W(4)+NUM(I)
      WRITE(3,104) W
      DO 9 I=1,4
9     W(I)=W(I)*RATIO
      WRITE(3,105) W
      X2=1.E10
      DO 11 J=1,J1
```

Figure 2

SUBROUTINE SORT1

```
      X1=0.
      DO 10 K=1,4
10    X1=X1+(W(K)-Z(J,K))**2
      IF(X1.GT.X2) GO TO 11
      X2=X1
      J0=J
11    CONTINUE
      IF(X2.LT.X0) 12,14
12    Z(J0,5)=Z(J0,5)+1
      WRITE(3,106) J0,(Z(J0,K),K=1,4)
      DO 13 K=1,4
13    DELT(K)=(W(K)-Z(J0,K))/Z(J0,K)
      WRITE(3,107) DELT,X2
      GO TO 3
14    J1=J1+1
      Z(J1,5)=1.
      DO 15 K=1,4
15    Z(J1,K)=W(K)
      WRITE(3,108) J1,(Z(J1,K),K=1,4)
      GO TO 3
16    WRITE(3,109)     (Z(J,5),J=1,J1)
94    FORMAT(1H1,5X,*XRAY SEPARATION=*,E10.3/)
95    FORMAT(2E10.3)
96    FORMAT(16I5)
97    FORMAT(/5X,4A10/)
98    FORMAT(4A10)
99    FORMAT(I4)
104   FORMAT(2X,*SAMPLE   *,9F10.0/)
105   FORMAT(2X,*NORMAL   *,9F10.4)
106   FORMAT(2X,*CLASS *,I2,9F10.4)
107   FORMAT(2X,*DIFFER   *,10F10.4/)
108   FORMAT(2X,*NEW *,I2,2X,9F10.4/)
109   FORMAT(2X,*TOTALS   *,10F5.0)
      END
```

Figure 2

SUBROUTINE SORT1

Table 1 Dictionary of Variables

BACK	Backscatter count (channels 3-9 inclu.)
DELT(4)	Ratio of Difference between sample and class component to class component
I	Index of channel
IL	Sample index (ends run if zero)
J	Index of class
JØ	Index of closest class.
J1	Number of established classes
K	Index of component
NUM(64)	Input channel counts.
RATIO	Reciprocal of BACK
TITLE(4)	40-character title of sample
W(4)	Component of sample
XØ	Input separation
X1	Separation of class under consideration
X2	Separation of closest class
Z(40,5)	Components of established classes

```
 XRAY SEPARATION= 1.000E+00

  0000002107201

SAMPLE        26027      970     1376      957
NORMAL      12.3702    .4610    .6540    .4548
NEW   1     12.3702    .4610    .6540    .4548

  000000000000000002107202

SAMPLE        22853     2577     4869     2291
NORMAL      10.9976   1.2401   2.3431   1.1025
NEW   2     10.9976   1.2401   2.3431   1.1025

  0000000000000000*02107203

SAMPLE        20224     4831     9294     4010
NORMAL       9.0813   2.1693   4.1733   1.8006
NEW   3      9.0813   2.1693   4.1733   1.8006

  0000000000000000*02107204

SAMPLE        20226     4988     9544     4038
NORMAL       8.6621   2.1362   4.0874   1.7293
CLASS  3     9.0813   2.1693   4.1733   1.8006
DIFFER       -.0462   -.0153   -.0206   -.0396     .1893

  0000000000000000*02107205

SAMPLE        18853     6425    12561     5072
NORMAL       7.9448   2.7075   5.2933   2.1374
NEW   4      7.9448   2.7075   5.2933   2.1374

  000000000000000*02107206

SAMPLE        18573     5767    11145     4779
NORMAL       8.3026   2.5780   4.9821   2.1363
CLASS  4     7.9448   2.7075   5.2933   2.1374
DIFFER        .0450   -.0478   -.0588   -.0005     .2417

  0000000000000000*02107207

SAMPLE        18503     7412    13987     5685
NORMAL       7.8837   3.1581   5.9595   2.4222
CLASS  4     7.9448   2.7075   5.2933   2.1374
DIFFER       -.0077    .1664    .1259    .1333     .7317
```

Figure 3

SAMPLE PROGRAM PRINTOUT

followed by the actual sample counts for each component, followed by the actual sample counts for each component, followed by these values after being normalized by dividing by the backscatter count. The next line is then the components of a new class having the same normalized count or a statement showing what class the sample was found to belong. The fourth line shows the fractional difference between the sample and the class to which it belongs.